Effectiveness of Wildlife-Fencing in Reducing Crashes in the Intermountain West Region

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16. Abstract

Wildlife-vehicle collisions (WVCs) pose serious risks to motorist safety and contribute significantly to wildlife mortality. Wildlife-fencing serves as a proven countermeasure to mitigate WVCs while promoting habitat connectivity. This study evaluates the safety effectiveness of wildlife-fencing installed across Colorado, Idaho, Nevada, Utah, and Wyoming from 2010 to 2024, using traffic volume, migration patterns, and urban/rural context as explanatory variables. A total of 620 miles of treated sites and 766 miles of matched control sites were analyzed using empirical Bayes (EB) methods. The EB results indicate a crash modification factor (CMF) of 0.27 for total WVCs, corresponding to a 73% reduction, with a standard error of 0.019 and a 95% confidence interval of (0.23, 0.30). For fatal and injury (KABC) WVCs, the CMF was 0.12 corresponding to an 88% reduction, supported by a standard error of 0.020 and a 95% confidence interval of (0.08, 0.16). Property-damage-only (PDO) crashes showed a CMF of 0.28, representing a 72% reduction, with a standard error of 0.022 and a 95% confidence interval of (0.24, 0.33). Carcass data provided an independent validation of these crash-based findings. The carcass CMF of 0.13 indicates an 87% reduction in observed carcasses, with an exceptionally small standard error of 0.005 and a tight 95% confidence interval of (0.12, 0.15). Findings support continued investment in targeted safety interventions across migration corridors. Economic analysis yielded a benefit-cost ratio of approximately 2.6 (at a 3% discount rate), confirming that wildlife-fencing is an effective and cost-efficient strategy for improving roadway safety.

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Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AIC	Akaike Information Criterion
BACI	Before-After-Control-Impact
CMF	Crash Modification Factor
CDOT	Colorado Department of Transportation
DVC	Deer-vehicle collision
DOT	Department of Transportation
EB	Empirical Bayes
EVC	Elk-vehicle collisions
FHWA	Federal Highway Administration
GIS	Geographic Information System
GLM	Generalized linear models
HSIP	Highway Safety Improvement Program
ITD	Idaho Transportation Department
ML	Main line
MVC	Moose-vehicle collisions
NB	Negative Binomial
NDOT	Nevada Department of Transportation
PDO	Property Damage Only
SPF	Safety Performance Function
UDOT	Utah Department of Transportation
U.S. DOT	United States Department of Transportation
UVC	Ungulate-vehicle collision
WVC	Wildlife-vehicle collision
WYDOT	Wyoming Department of Transportation

Executive Summary

Wildlife-Vehicle Collisions (WVCs) are a significant safety concern for vehicles and are a major source of wildlife mortality. Wildlife-fencing is a safety countermeasure to mitigate WVCs and enhance wildlife conservation efforts. Across the Intermountain West, Utah, Wyoming, Nevada, Colorado, and Idaho typically use 7-8 foot ungulate-exclusion fencing. The intent of this project is to determine the effectiveness of wildlife-fencing installation in reducing WVCs, including the development of crash modification factors (CMFs) for WVCs.

A crash data analysis was conducted using WVC data from 5 western states: Colorado, Idaho, Nevada, Utah, and Wyoming. Coordination was performed with each state department of transportation (DOT) to evaluate the effectiveness of wildlife-fencing as a mitigation countermeasure, in terms of CMFs. Reported WVCs from 2010 to 2024 and carcass data from the same period were obtained from the DOTs. The project team identified highway locations and projects where wildlife-fencing was installed, with emphasis on projects constructed between 2011 and 2023 such that adequate before/after data could be established. The average number of before years for the treatment locations in this study is 8.67 years and the average after treatment period is 5.16 years. Additional comparison sites also known as control segments were also identified where wildlife-fencing has or is being considered. The project team performed data collection at the identified project locations, which included gathering information about the type of fencing installed, locations of available animal crossings, crash history, carcass data, and traffic volume, among others. Finally, safety performance functions (SPFs) were developed, and CMFs calculated using the empirical Bayes (EB) methodology for wildlife crash types. Separate SPFs and CMFs were calculated for WVCs and carcass data. Understanding the safety effectiveness of wildlife-fencing is essential for promoting both public safety and biodiversity and grows in importance as road networks increasingly intersect natural habitats. This study investigated the safety effectiveness of existing wildlife-fencing installed in the five states between 2010 and 2023. Additionally, traffic volume, wildlife herd size, migration area usage type, and urban versus rural location types were included as explanatory variables for SPFs.

The study evaluated 148 segments (620 miles) of treated roadways with wildlife-fencing installations and 453 segments (826 miles) of unfenced roadways for control sites with similar characteristics. A CMF is a numerical estimate that describes a safety treatment that is expected to affect crash frequency. A CMF less than one means fewer expected crashes in the future; a CMF greater than one means more expected crashes in the future. EB results indicate a CMF of 0.27 for total wildlife-related crashes, corresponding to a 73% reduction, with a standard error of 0.019 and a 95% confidence interval of (0.23, 0.30). For fatal and injury (KABC) crashes, the CMF was 0.12, indicating an 88% reduction, supported by a standard error of 0.020 and a 95% confidence interval of (0.08, 0.16). Property-damage-only (PDO) crashes showed a CMF of 0.28, representing a 72% reduction, with a standard error of 0.022 and a 95% confidence interval of (0.24, 0.33). These narrow confidence intervals and low standard errors reinforce the statistical reliability and precision of the findings. Carcass data provided an independent validation of these crash-based findings. The carcass CMF of 0.13 indicates an 87% reduction in observed carcasses, with an exceptionally small standard error of 0.005 and a tight 95% confidence interval of (0.12, 0.15). This high precision reinforces that wildlife-fencing substantially reduces wildlife presence on or near the roadway, complementing the reductions observed in crash outcomes.

The project team conducted a benefit-cost analysis for wildlife-fencing, offering a more empirical approach than previous methods. Traditionally, wildlife mitigation projects have been justified using only crash history and speculative assumptions about crash reduction benefits. The economic analysis indicates that the implementation of wildlife-fencing will yield benefit-cost ratios of approximately 2.6 with a 3% discount rate. The findings provide transportation agencies with robust, data-driven justification for investing in wildlife-fencing as a proven safety measure. The project enhanced the justification for wildlife-fencing, offered a framework for evaluating future projects, and contributed to both transportation safety.

1. Introduction

Chapter 1 of this report provides the problem statement, objectives, and scope of this research study. It also outlines the rest of the study report.

1.1. Problem Statement

Approximately 29,000 injuries and 200 fatalities occur annually due to wildlife-vehicle collisions (WVCs) in the U.S. (IIHS, 2020; NHTSA, 2021). More than two to three million WVCs occur each year in the U.S., and the estimated economic impact of WVCs is approximately $10 billion annually (Nevada Department of Transportation, 2022). The consequences of WVCs extend beyond immediate human safety concerns. WVCs result in significant economic costs, including vehicle damage, medical expenses, and increased insurance premiums. The WVC Reduction Study, by the Federal Highway Administration (FHWA), found that 12 federally endangered or threatened species are directly imperiled by U.S. roadways (Huijser, M.P., et al., 2008).

A general upward trend in deaths from collisions with animals occurred from 1975 to the mid-2000s. Deaths increased from 89 in 1975 to 223 in 2007, with the latest available data of 184 deaths in 2022. In 2022, the highest number of deaths from collisions with animals occurred July-September (IIHS, 2023). More recent data from State Farm suggests that the most dangerous months for WVCs are, in order, November, October, and December (State Farm 2024).

The impact of WVCs on safety and wildlife populations has been receiving increased attention. Mitigation efforts often focus on reducing collisions with large hooved mammals such as deer. Auto insurance estimates indicated that U.S. motorists had a 1 in 128 chance of colliding with an animal in 2024. State Farm estimated that more than 1.8 million auto insurance claims involving WVCs were filed across the industry from July 1, 2023, to June 30, 2024. Deer-vehicle collisions (DVCs) are estimated to be among the costliest collision types in Virginia, averaging more than $533 million per year (Donaldson, 2017).

Wildlife-fencing, such as barrier/exclusionary or funnel fencing, is a safety countermeasure to mitigate WVCs. Understanding the safety effectiveness of wildlife-fencing is essential for promoting public safety and biodiversity, and mitigation measures grow in importance as road networks increasingly intersect natural habitats. WVCs are a significant safety concern and a major source of wildlife mortality globally. Previous studies have evaluated the effectiveness of wildlife-fencing in reducing WVCs but have been limited to spot site locations. A 2025 study by the current authors produced a viable crash modification factor (CMF) for WVCs in Utah (Shea and Goswamy, 2025), but it is unknown how applicable these findings are to other states. The implementation of wildlife-fencing aims to mitigate WVCs by preventing wildlife from accessing roadways, or guiding wildlife to grade separated crossings, thereby protecting both human life and animal populations. WVCs are a significant and growing concern, posing risks to both human safety and wildlife populations. As road networks expand and urban areas encroach on natural habitats, understanding the patterns, impacts, and mitigation strategies related to WVCs has become increasingly important.

The Utah Department of Transportation (UDOT) receives more than 3,000 reports of wildlife killed by vehicles annually. In Colorado, WVCs are a significant safety concern, ranking as the third leading cause of motor vehicle crashes in the state (Utah Division of Wildlife Resources, 2023.)

On average, Colorado sees approximately 4,000 reported WVCs annually. In 2024, the Colorado State Patrol alone investigated 3,573 such incidents. These collisions result in an estimated $80 million in annual property damage and medical costs. Between 2010 and 2024, wildlife collisions caused 48 human deaths and more than 5,000 injuries in the state (Colorado DOT, n.d.)

WVCs are a major safety concern in Wyoming, with more than 7,600 ungulates hit annually, representing about 15% of all state traffic crashes. Collisions often peak at dawn and dusk, predominantly involving mule deer. In the past 15 years, these incidents have doubled, with roughly 21 ungulates killed daily. Deer accounts for 87% of collisions, followed by elk and pronghorn. The highest risk periods are fall and spring due to migration, particularly during dawn and dusk. These collisions result in significant vehicle damage and, in some cases, human injury or death (Riginos, C., 2022).

In Idaho, WVCs account for approximately 1 in 5, or roughly 20% of all traffic crashes, making it a major safety concern. There is an average of more than 1,000 crashes involving wildlife on Idaho highways and interstates annually. These crashes cause 1 to 4 human fatalities in most years. From 2014-2023, large ungulates (hoofed animals) dominated the reported statistics: 67% were mule deer, 16% elk, and 7% moose. The highest number of crashes occur during spring and fall migrations (May and October), particularly from dusk to dawn. Idaho is ranked as a "medium risk" state for animal-vehicle collisions, with a 1 in 154 chance of a driver hitting an animal in 2025-2026 (Idaho Transportation Department, n.d.).

In Nevada, more than 500 WVCs are reported annually, costing more than $19 million in damages and killing roughly 5,000 animals. Due to significant underreporting (estimated at less than 10%) of the actual number of crashes, the total is likely much higher. DVCs spike 300% during fall months, particularly when daylight saving time ends, due to increased animal activity at dusk (Nevada Department of Transportation, n.d.).

1.2. Objectives

The intent of this project is to establish a CMF for wildlife-fencing installation. The CMF was developed using the CMF Clearinghouse guide, which includes guidance for accuracy, precision, and general applicability of results (FHWA, 2021). Common characteristics of a high-quality CMF include statistically rigorous reference groups, adequate sample size, diverse geographies and sites, small standard errors, and controls for potential bias.

The study analyzed historical data on WVC severity in the five western states of Colorado, Idaho, Nevada, Wyoming, and Utah. It examined the distribution of crash severities. Crash severity was coded using the FHWA KABCO injury classification scale, which categorizes crashes into fatal (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C), and property-damage-only (O) outcomes and compared WVC outcomes to other crash type distributions and economic cost. The study also identified a benefit-cost ratio for installing wildlife-fencing. Wildlife-fencing projects are currently identified and prioritized using only crash history with an expectation that crashes will reduce after installing the fencing. This project helps quantify the expected reduction in crashes and associated economic benefit, thus providing a comparison of safety benefits to other safety projects. The study also provides a historic severity distribution for WVCs and compares that severity distribution to other crash types.

1.3. Scope

The project had three main activities. The project team first identified highway locations and projects where wildlife-fencing has been installed, with emphasis on projects constructed between 2011 and 2023 such that before/after data could be established. Additional comparison sites were also identified where wildlife-fencing is not installed. The project team then collected project location data from the different state DOTs, which included gathering information about the type of fencing installed, locations of available animal crossings, crash history, carcass data, and traffic volume, among others. Finally, an EB statistical analysis was performed as a before/after study to determine the CMF.

1.4. Outline of Report

This report includes six chapters. The Introduction outlines the research needs and objectives of this research. The Literature Review chapter reviews existing research. The Data Collection chapter identifies the locations, data collection, and summary of statistics. The Methodology and Results chapter describes the data utilization and statistical methodology along with the results from the analysis. The Conclusions chapter includes a summary of findings. The Recommendations and Implementation chapter provides an implementation strategy for using the CMF and results for prioritizing future wildlife-fencing projects.

2. Literature Review

2.1. Overview

This chapter includes a literature review of relevant research as well as a discussion of before/after studies that inform the statistical methodology used for this research.

2.2. Literature Review

Fencing is one of the most applied measures to separate wildlife from motorists (Romin et. al. 1996). Wildlife-fencing typically consists of 6.0-8.0 foot (2.0-2.4-m)-high wire mesh fence material. Installers typically set either wooden or metal posts, relying on metal posts where the fence must be anchored over rocky ground.

Wildlife-fencing is effective at reducing WVCs but may increase the barrier effect of the road. A 94 to 97% reduction in ungulate-vehicle collisions (UVCs) was observed along fenced sections of the Trans-Canada Highway (Woods 1990). Other locations showed wildlife-fencing was effective in reducing UVCs by 80% (Clevenger et al., 2001). Dodd and others found that wildlife-fencing in combination with underpasses reduced elk-vehicle collisions (EVCs) by 86.8% (Dodd et. al, 2007). Reed reported an average reduction of 78.5% for DVCs in Colorado, and Ward reported a reduction of greater than 90% for DVCs in Wyoming (Reed et. al., 1982, Ward et. al., 1982). Clevenger identified that more WVCs were closer to fence ends than expected by chance; however, access points (fence gaps) did not create WVC hotspots along the Trans-Canada Highway in Banff National Park, Alberta (Clevenger et al., 2002).

Adding fences along a highway to connect existing underpasses is an effective way to enhance existing infrastructure. Approximately 0.994 miles (1.6 km) of 8-foot (2.4-m) high wildlife-fencing was added to connect two existing underpasses, situated approximately 5 miles (8 km) apart on Interstate 64 in Virginia (Donaldson et al., 2021). The two underpasses consisted of a bridge underpass and a large box culvert. The study used cameras to monitor animal crossings for 2 years after wildlife-fencing was installed and compared the crossing data with 2 years of collision data prior to the fence being installed. After wildlife-fencing installation, DVCs were reduced by 96.5% at the box culvert and 88% at the bridge underpass, and there were no increases in DVCs within 1.6 km of the fence ends. Deer crossings increased 410% at the box culvert and 71% at the bridge underpass. Use of the culvert and bridge underpasses by other mammals increased by 81% and 165%, respectively.

Studies conducted in the southwestern United States have shown that wildlife-fencing to connect existing underpasses is an effective means of reducing WVCs regardless of whether the underpasses are designed for wildlife. The benefits from crash reduction exceeded the fencing costs in 1.8 years, and fencing resulted in an average saving of greater than $2.3 million per site over the 25-year life expectancy of the fencing (Donaldson et al. 2020). The study found that the addition of wildlife-fencing to certain existing isolated underpasses can be a highly cost-effective means of increasing driver safety and enhancing habitat connectivity for wildlife. Other studies show DVCs were reduced by 92% on average after fence installation, with deer crossings increasing significantly at the underpasses. EVCs were reduced by 85 to 97% in Arizona after wildlife-fencing was constructed to connect wildlife crossing structures (Dodd et al. 2007, Gagnon et al. 2010). Similarly, EVCs decreased by 97% after the height of

0.9-m fencing was increased to 2.4 m between two large bridges and interchanges along I-17 in Arizona; the use of these bridges by elk increased by 217% and 54% (Gagnon et al. 2015).

The success of wildlife crossings (overpasses or underpasses) with wildlife-fencing was studied to compare the costs of construction to effectiveness at reducing WVCs (Clevenger and Huijser 2011, Kintsch et al. 2020). Implementation of wildlife crossings reduced DVCs and EVCs by more than 80% overall, with reductions of more than 90% observed in several studies (Kintsch et al. 2020).

Appropriate application of wildlife-fencing leads to substantial decreases in wildlife mortality and injury crashes, thereby enhancing road safety (Huijser et al., 2008). Wildlife-fencing can be designed to prevent large animals from accessing the road right-of-way by properly considering the following factors:

- Height and Visibility: Wildlife-fencing should typically be at least 8 feet (2.4 meters) high to prevent large mammals from jumping over. Visibility markers (e.g., flags or reflective tape) can help reduce collisions with the fence, especially for birds and fast-moving animals.
- Wildlife Crossings: Dedicated wildlife underpasses or overpasses are preferred. These structures should be strategically placed based on known animal movement patterns and migration corridors, and wildlife-fencing should funnel animals toward these safe crossing points.
- Location and Placement: Analyze the landscape features and habitats that need to be reconnected to provide suitable locations for wildlife passages. Wildlife-fencing should be provided in areas where collisions are particularly common and should guide animals to safe crossing points.
- Materials and Maintenance: Regular maintenance is essential to keep the fence effective and safe for wildlife.
- Ecological Impact: Assess the potential ecological impact of wildlife-fencing, particularly in areas of major ecological interest, such as habitats of endangered species or ecological corridors. Mitigation measures should be implemented to avoid any adverse impacts.

By considering these factors, wildlife-fencing can be designed to effectively reduce wildlife mortality and enhance road safety while maintaining ecological balance. Fence designs vary and may include shorter "drift" fences for amphibians or taller fences designed for large mammals (Boyle et al., 2021). Fencing may be accompanied by wildlife crossing structures, which maintain or restore wildlife movement across the highway. Because of cost, fencing is usually prioritized along road segments or WVC "hotspots" (Huijser et al., 2016).

Several factors influence the effectiveness of reducing WVCs, such as fence design and installation, wildlife crossing design, species-specific considerations, and maintenance and monitoring. The type of fence used, whether it is wire mesh or solid barriers, and its height are critical for preventing wildlife from penetrating the roadway. Crossings need to be designed to accommodate the size and behavior of the local species. Larger mammals, like deer, may be deterred by tight spaces or high fencing, whereas smaller animals may require culvert crossings and guide fencing with a smaller grid pattern. Additionally, fences can become damaged or degraded over time, reducing their effectiveness in preventing animal crossings. Regular maintenance and monitoring are essential to keep wildlife-fencing effective (Clevenger & Waltho, 2000; Huijser et al., 2016; McCollister & Van Manen, 2010).

Improving underpasses can mitigate WVCs and improve habitat connectivity. Adding wildlife-fencing along the roadway to guide animals toward underpasses significantly reduces WVCs, with one study finding a 50-70% reduction in WVCs (Clevenger et al.,2001). The effectiveness of wildlife-fencing was significantly enhanced when combined with wildlife crossings such as underpasses and overpasses. This enhancement protects wildlife and facilitates better movement between habitats, ultimately contributing to ecosystem health. Another study found that wildlife-fencing led to a 90% reduction in WVCs (Huijser et al., 2008). Some studies highlight the importance of infrastructure modifications in wildlife conservation efforts, and in maintaining fences to prevent wildlife from entering the roadway. For example, research on the A50 highway in the Netherlands indicated a reduction in WVCs by as much as 70% after the installation of wildlife-fencing (LiquiSearch, n.d.). The study also highlighted the importance of monitoring fence integrity and ensuring that fencing was continuous and without gaps. The distance between underpasses also influences animal habitat. Some animal species are less likely to reach an underpass when traveling along longer exclusionary fence lines (McCollister and Van Manen 2010). Wildlife-fencing can adversely affect populations that access resources on both sides of the road when the fencing is not combined with an accessible underpass (Jaeger and Fahrig 2003).

The design of fence ends is particularly important to minimize "end runs," whereby an animal circumvents the fencing by traveling from the habitat side of the fence end to the roadside. Clevenger et al. (2001) found an increase in UVCs within one km of fence ends, although the authors concluded that major drainages near the fence end likely influenced these occurrences. Conversely, Bissonette and Rosa (2012) and Gagnon et al. (2015) found no increases in WVCs at fence ends. The risk of end runs can be minimized by tying the fence ends into areas of steep topography or other obstacles that create difficulty for the animal to circumvent the fence end (Huijser et al. 2015, Jared et al. 2017).

In Sweden, wildlife-fencing reduced moose-vehicle collisions (MVC) by 80%. In the U.S., Boarman et. al. (1996) found 93% fewer tortoise carcasses and 88% fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway. The study was conducted in the Mojave Desert of California, along Highway 58. In British Columbia, an 8-foot (2.4-m) exclusionary fence was 97 to 99% effective at reducing crashes with large wildlife. In Pennsylvania, Feldhamer and others determined that an 8.9 foot (2.7-m) high fence was more effective than the 7.2 foot (2.2-m) high fence. Pennsylvania saw that deer breached the fence despite changing the height of fences. Feldhamer suggested fencing may be effective if properly maintained to fix holes damaged by people, and by decreasing the size of the openings on the woven wire mesh.

Ahmed et al. 2022 estimated the CMFs for WVC countermeasures, crossing structures with wildlife-fencing, and wildlife warning signs using cross-sectional analysis. The study used carcass removal data and traditional crash data and estimated CMFs of 0.66 and 0.55 using carcass data and crash data, respectively. The results also suggested that implementing wildlife warning signs at WVC hotspots has been ineffective, but the crossing structures are found to be effective. Table 2-1 summarizes key literature related to wildlife-fencing.

Table 2-1 Wildlife-Fencing Literature Review List

--	Study	Authors	Location	Findings
1	Wildlife-Vehicle Collision Reduction Study: Report to Congress	M.P. Huijser, P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, and R. Ament	USA	Wildlife-fencing may reduce road mortality by 80–99%.
2	Enhancing Existing Isolated Underpasses with Fencing to Decrease Wildlife Crashes and Increase Habitat Connectivity	Bridget M. Donaldson and Kaitlyn E.M. Elliott	Arizona	After wildlife-fencing installation, DVCs were reduced by 92% on average (96.5% and 88% at the box culvert and bridge underpass, respectively).
3	Investigating the Safety Effectiveness of Wildlife–Vehicle Crash Countermeasures using a Bayesian Approach with a Comparison between Carcass Removal Data and Traditional Crash Data	Irfan U. Ahmed and Mohamed M. Ahmed	Wyoming	The crossing structures with wildlife-fencing are found to be effective, with an estimated CMF of 0.66 and 0.55 using carcass data and crash data, respectively.
4	Enhancing Existing Isolated Underpasses with Fencing Reduces Wildlife Crashes and Connects Habitat	Bridget M. Donaldson and Kaitlyn E. M. Elliott	Virginia	DVCs were reduced by 96.5% and 88% at the box culvert and bridge underpass respectively. Valued a DVC at $8,936. 99% of the deer carcasses as Property Damage Only (PDO) and 1% minor injury crashes.
5	Role of Fencing in Promoting Wildlife Underpass Use and Highway Permeability	Dodd, N. l., Gagnon, J. W., and Boe, S et al.	Arizona	EVC incidence declined by 87% after wildlife-fencing installation. Used crossing rates and passage rates. The proportion of elk crossings that occurred along fenced highway stretches declined 50% while the proportion of crossings along unfenced highways increased 40%. Wildlife-fencing plays an important role in reducing the incidence of WVCs and increasing the effectiveness of wildlife passage structures.
6	Advances in Wildlife Crossing Technologies	Mary Gray	NA	Latest tools to reduce animal-vehicle collisions and save the lives of both motorists and animals.
7	Impact Of Road Fencing on Ungulate–Vehicle Collisions and Hotspot Patterns	Andrius Kucas and Linas Balciauskas	Lithuania	Assessed the effect of annual average daily traffic (AADT) and wildlife-fencing on UVCs using regression analysis of changes in annual UVCs and UVC hotspots on different categories of roads.
8	Deer–Vehicle Collision Prevention Techniques	Lauren L. Mastro, Michael R. Conover, and S. Nicole Frey	Utah	Despite a limited amount of data, multiple studies have shown that properly installed and maintained fences combined with wildlife crossings are the most effective method of reducing DVCs.
9	Construction Guidelines for Wildlife-Fencing and Associated Escape and Lateral Access Control Measures	Marcel P. Huijser, Angela V. Kociolek, Tiffany D.H. Allen, and Patrick Mcgowen	Various	Describes the current state of knowledge and practice regarding the design, implementation, and maintenance of wildlife-fencing and associated escape and lateral access control measures.
10	Implementing Wildlife-Fences Along Highways at the Appropriate Spatial Scale: A Case Study of Reducing Road Mortality of Florida Key Deer	Marcel P. Huijser and James S. Begley	Florida	The before-after-control-impact (BACI) analysis showed that wildlife-fencing was highly effective (95%) in reducing DVCs along the mitigated highway section.

2.2.1. Patterns and causes of WVCs

WVCs are more prevalent in certain geographic areas and at specific times of the year, particularly regions where wildlife habitats intersect with major roadways. Huijser et al. (2009) highlights that the rural areas with high wildlife populations, such as parts of the Midwest and West, experience higher rates of WVCs. Seasonal patterns also contribute to the occurrence of WVCs, with peaks observed during spring and fall, coinciding with animal migrations and breeding behaviors.

Key factors contributing to WVCs include roadway characteristics, vehicle speed, and wildlife behavior. High-speed roads increase the likelihood of fatal collisions, as the reaction time for drivers decreases. Additionally, certain species, such as deer, are more frequently involved in WVCs due to their behavior and habitat preferences.

2.2.2. Mitigation Strategies of Different States

In 2012, the Wyoming DOT completed construction of two wildlife overpasses and six underpasses, along with 12 miles of wildlife-fencing to lead animals to these crossings above or below the highway. In the three years after construction, tens of thousands of animals used the structures and WVCs were reduced by 80%. The project also contributed to healthier populations of migrating animals by allowing them to safely cross the highway.

A Colorado project completed in 2016 included two wildlife overpasses, five underpasses, a widened shoulder, and wildlife-fencing with “escape ramps” for animals. The changes reduced crashes by almost 90% on Highway 9 through the Blue River Valley by the second winter following construction. The study indicated the safety benefit of the project will pay for construction costs by around 2036.

California is working on the Wallis Annenberg Wildlife Crossing which will be the largest wildlife crossing in the world, scheduled to be completed in Fall 2026. The crossing will stretch across 10 lanes of traffic that crisscross across habitat that is home to an abundance of wildlife including a state protected species of mountain lion, 25 of which have been killed crossing these lanes prior to this project.

2.2.3. Cost-Benefit Analysis

WVCs represent a significant and growing safety, economic, and ecological concern in Wyoming. According to Impacts of Roadways on Wildlife in Wyoming: Long-Term and Recent Trends, the annual number of reported WVCs has steadily increased over time, with a current five-year (2016-2020) average of approximately 7,656 collisions per year. Most of these crashes involve large ungulates, particularly mule deer which account for roughly 72% of all WVCs statewide. On average, Wyoming experiences 21 ungulate collisions per day. Importantly, the report notes that observed crash totals likely underestimate true mortality, as many injured animals move away from the roadway and are not recorded in official datasets (Riginos, 2022).

In addition to safety concerns, WVCs impose substantial economic costs. The total annual cost of WVCs in Wyoming is estimated to average approximately $55 million, reflecting expenses associated with vehicle damage, emergency response, medical treatment, lost productivity, and wildlife losses. These costs have more than doubled over the past 15 years and are projected to double again by 2035 if no additional mitigation measures are implemented. Increasing traffic volumes are further exacerbating the problem by making roadways both more dangerous for motorists and more difficult for wildlife to cross, contributing to habitat fragmentation and disruption of migration routes. The report emphasizes that targeted mitigation strategies such as wildlife-fencing combined with crossing structures have proven highly effective at reducing collisions at identified hotspots, underscoring the importance of addressing WVC through systematic planning and investment (Riginos, 2022). Several studies have conducted cost-benefit analyses of wildlife-fencing. Huijser et al. (2008) found that the reduction in vehicle damage, medical costs, and human fatalities due to fewer crashes often outweighed the cost of installing wildlife-fencing and crossings. The authors concluded that investing in wildlife-fencing is economically justifiable in high-collision areas. Specific findings include:

- Direct Costs: WVCs result in significant direct costs, including vehicle repair, medical expenses, and the loss of wildlife. These costs can be substantial, especially when larger animals like deer or elk are involved.
- Indirect Costs: Indirect costs include traffic delays, emergency response, secondary crashes, and the impact on local economies. These costs can be difficult to quantify but are nonetheless significant.
- Cost-Benefit Analysis: Cost-benefit analyses of various mitigation measures, such as wildlife crossings and fencing, can be conducted. These measures can be expensive to implement, but the long-term benefits, including reduced WVCs and reduced loss of wildlife, can outweigh the costs when crash frequency and severity is sufficiently reduced.

The estimated cost of the average WVC based on property damage, human injuries, and human fatalities is $6,126. Over 95% of all WVCs result in property damage only (PDO) crashes as shown in Table 2-2, with the average cost per incident estimated at $2,451 (Huijser et al., 2008).

Table 2-2 Average WVC Cost

Crash Severity	Crash Cost ($)	Distribution of Collisions (%)	Contribution of Cost of Average WVC ($)
Property damage only	2,570	95.4	2,451
Possible human injury	24,418	2.3	572
Evident human injury	46,266	1.8	809
Incapacitating/severe human injury	231,332	0.5	1,083
Human fatality	3,341,468	0.04	1,210

One study estimated that WVCs result in an average of 0.05 human injuries when colliding with deer, 0.10 human injuries for elk, and 0.20 human injuries for moose (Huijser et al., 2008). These proportions combined with the relative frequency for each of the three injury categories (51.4% for possible injuries, 38.4% for evident injuries, and 10.3% for incapacitating or severe injuries)result in the cost estimates for human injuries by species presented in Table 2-3. The research emphasizes mitigation measures to reduce the economic impact of WVCs and improve safety for humans and wildlife.

Table 2-3 Cost Estimate per Crash for Human Injuries by Species

Type of Human Injury	Deer	Elk	Moose
Possible	$627	$1,254	$2,508
Evident	$887	$1,775	$3,550
Incapacitating/Severe	$1,187	$2,374	$4,749
Total	$2,702	$5,403	$10,807

2.3. Wildlife-Fencing Studies

Idaho has implemented several wildlife-fencing projects that demonstrate the effectiveness of exclusionary and wildlife-friendly fencing in reducing WVCs and improving wildlife movement across highways. Along State Highway 21, Idaho Department of Fish and Game (IDFG) installed more than half a mile of wildlife-exclusion fencing in 2010 to funnel mule deer and elk toward a designated underpass at MP 18.2, a corridor used by more than 7,000 deer and 1,000 elk annually. Project evaluations show that exclusion fencing in this area significantly reduced collision risk by preventing animals from accessing the roadway and increasing use of the crossing structure (IDFG, 2011). The Cervidae Peak Wildlife Overpass east of Boise incorporated extensive exclusion fencing to guide animals toward the structure, addressing high collision rates involving 8,000 to 9,000 mule deer and 1,800–2,400 elk during seasonal migrations. Together, these findings indicate that wildlife-fencing is an effective mitigation tool in Idaho when designed and implemented as part of an integrated crossing-structure system.

Nevada's wildlife-fencing efforts have focused primarily on mule deer migration routes and high-speed rural highways where WVC rates have historically been high. Along US-93 and I-80, the Nevada DOT (NDOT) installed wildlife exclusion fencing paired with underpasses and overpasses to reduce collisions and maintain connectivity for mule deer herds moving between seasonal ranges. Monitoring data from these corridors shows substantial reductions in WVCs, often exceeding 70%. Consistent use of these underpasses and overpasses by mule deer and other species has resulted in more than 50,000 documented mule deer crossings within the first several years of operation. These projects demonstrate that wildlife-fencing is a critical component of Nevada's strategy to reduce collisions and support long-term wildlife movement across arid, mountainous landscapes.

Wyoming's wildlife-fencing initiatives focus heavily on pronghorn and mule deer migration corridors, particularly in high collision areas along US-191, US-30, and the well-studied Trappers Point corridor. At Trappers Point, the Wyoming DOT (WYDOT) installed a combination of wildlife exclusion fencing and two wildlife overpasses, along with multiple underpasses to protect one of North America's longest ungulate migrations. Post-construction evaluations documented an 80% reduction in WVCs and a dramatic increase in successful pronghorn and mule deer crossings, with more than 40,000 documented crossings annually. Additional projects along US-189 and I-80 show similar results, with fencing preventing animals from accessing the roadway and channeling them toward designated structures. Wyoming's research underscores that fencing is essential for protecting long-distance migrations and is most effective when paired with structures designed to accommodate species-specific movement behavior.

Colorado has conducted extensive evaluations of wildlife-fencing and crossing structures, particularly along State Highway 9, US-285, and I-70. The SH-9 project near Kremmling is one of the most rigorously studied fencing-and-crossing systems in North America, with documented WVC reductions exceeding

90% and more than 100,000 mule deer crossings recorded within the first five years of operation. Colorado Parks and Wildlife (CPW) and Colorado DOT (CDOT) have published multiple technical reports and peer-reviewed studies demonstrating that exclusion fencing is essential for channeling mule deer, elk, and pronghorn toward overpasses and underpasses. These studies emphasize the importance of fence continuity, fence-end treatments, and species-specific structure design. Colorado's research provides strong, quantitative evidence that fencing is a critical component of effective wildlife-crossing systems.

Utah has one of the most well-documented wildlife-fencing research programs in the United States, with multiple peer-reviewed studies and long-term monitoring efforts led by the Utah Division of Wildlife Resources (UDWR) and Utah DOT (UDOT). Along US-89, US-6, and I-15, exclusion fencing paired with underpasses and overpasses has been shown to reduce WVCs by 70–90%, with several studies documenting more than 20,000 successful mule deer crossings annually. Research by Cramer, Bissonette, and others has demonstrated that fencing effectiveness increases substantially when escape ramps, jump-outs, and fence-end treatments are properly designed and maintained. Utah's published evaluations provide some of the strongest empirical evidence nationwide that wildlife-fencing, when integrated with crossing structures, significantly reduces collisions and maintains long-term wildlife movement across major highways.

Numerous studies have shown that wildlife-fencing, especially when paired with crossing structures, is highly effective in reducing WVCs. Crash reductions range from 80% to 99%, with notable successes reported in states like Arizona, Virginia, Florida, and Wyoming. Wildlife-fencing enhances motorist safety and promotes habitat connectivity by guiding animals to safe crossing points. Research approaches vary from crash data analysis and carcass removal tracking to hotspot modeling and EB evaluation, all pointing to the significant role fencing plays in minimizing WVCs and facilitating wildlife movement. Guidelines for design, implementation, and maintenance continue to evolve, supported by advancements in technology and best practices documented by Huijser, Donaldson, and Gray (Huijser et. al., 2016).

Research confirms that wildlife-fencing is one of the most effective countermeasures for reducing WVCs. Fencing, which is typically 6.6 to 7.9 feet (2.0 to 2.4 meter) high and made of wire mesh and is most effective when paired with underpasses or overpasses which provide safe wildlife crossings and enhance habitat connectivity. Studies in Virginia, Colorado, Arizona, and Canada show dramatic reductions in deer and elk collisions when fencing connects existing underpasses, even those not originally designed for wildlife. Fence design and placement are critical; poorly maintained or improperly designed fences can inadvertently create hazard zones or obstruct wildlife movement. Effective wildlife-fencing must consider species-specific needs, ecological context, and landscape features, incorporating elements like visibility markers, gates, and regular maintenance. Combining fencing with crossing structures improves ecosystem health and road safety, as well as connectivity for all animals especially where exclusionary fences may limit access to essential resources. Wildlife-fencing is a valuable strategy for mitigating the negative conflicts between wildlife and humans on roadways.

3. Data Collection

3.1. Overview

This chapter describes the data sources for WVCs and for carcass data used in the project. The chapter describes the extraction method used to identify and gather data for each state. The data collection process included compiling twelve categories of roadway, wildlife, and infrastructure information from each state. These categories consisted of roadway features, AADT data, crash data, carcass data, milepost start and end points for wildlife-fence projects, project cost, installation year, fence type, fence height, crossing locations and types, migration zone information, and rural/urban classification. All five states provided complete datasets for nearly every category, demonstrating strong consistency in regional data reporting. Overall, the participating states successfully submitted the requested information, enabling a comprehensive comparison of data availability across the region.

3.2. Data Collection Overall Process

Data for this study were collected from all participating states over several months, drawing primarily from each state's DOT along with supplemental information from publicly available GIS open-data portals and other relevant online sources. During this process, substantial variation in data formats, structures, and attribute definitions was encountered, requiring all datasets to be cleaned, standardized, and processed to meet the analytical requirements of the study. Treatment segments were identified first, and from these segments all relevant roadway, crash, and fencing attributes were extracted and prepared for analysis. Together, these steps established a consistent and reliable dataset that supported the subsequent evaluation.

Each study segment was independently verified using Google Street View to confirm the accuracy of the spatial information provided by the participating states. During this process, the start and end coordinates for every segment were crosschecked against the mapped locations, and adjustments were made when recent imagery showed changes in roadway configuration or fencing alignment. In addition to verifying geometry, the review also documented supplemental features observed in the imagery, such as the presence of escape ramps or other unique characteristics relevant to the analysis.

3.3. Data Preparation

The data preparation process involved a series of steps to build treatment and control datasets for analysis. The work began with identifying and segmenting all treatment locations. Multi-year AADT values were added to each treatment segment, and average before- and after-treatment AADT was calculated. Roadway characteristics and migration-zone information were integrated, and escape-ramp data collected to supplement the treatment attributes. Control segments were subsequently selected, after which AADT data for controls was gathered and roadway attributes added to for comparability. Before and after crash data was incorporated for both treatment and control sites. These steps established a complete dataset for the modeling and evaluation phases. Figure 3-1 shows a flowchart summarizing the data preparation process.

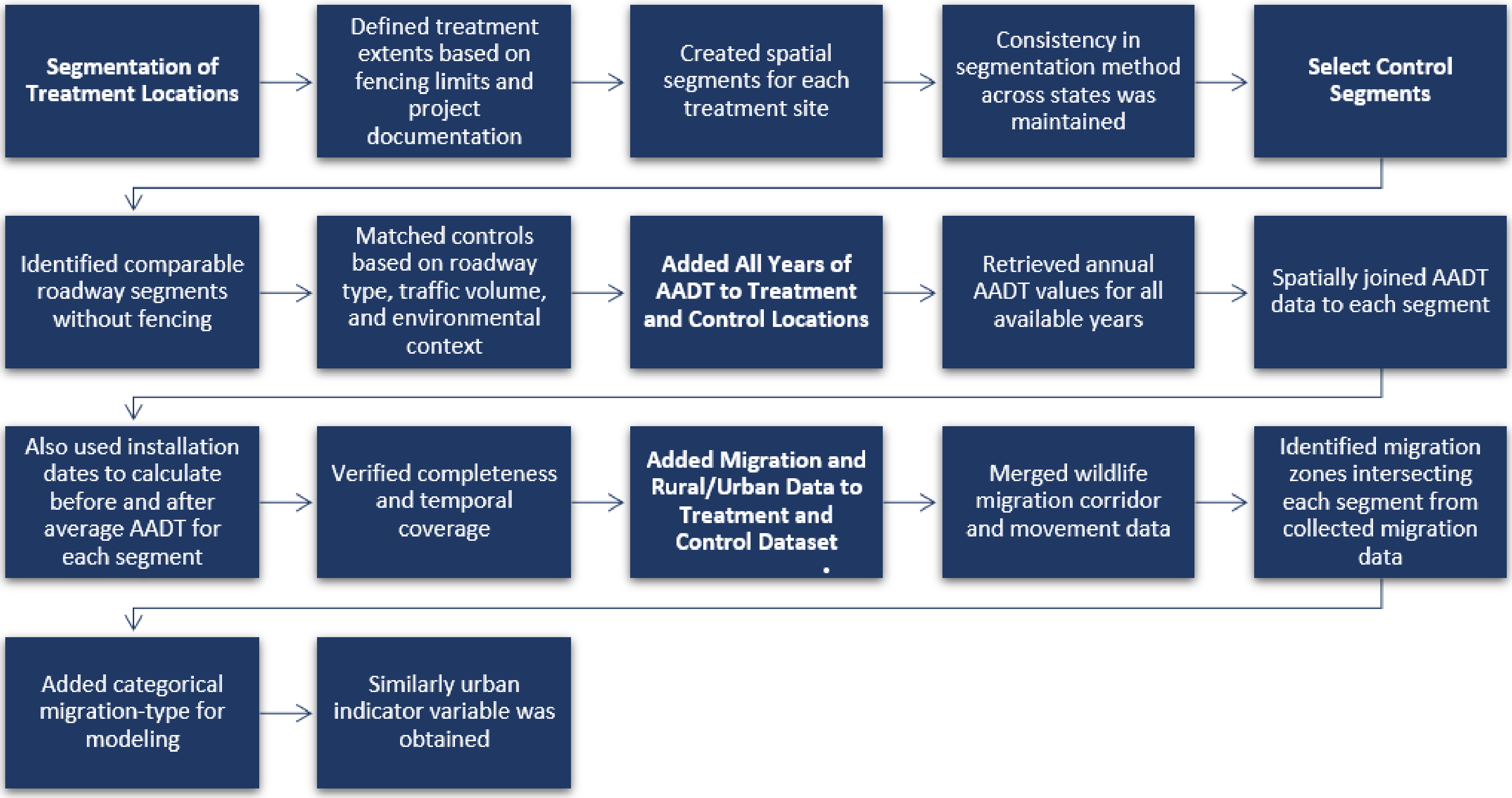


Figure 3-1 Data preparation process

3.4. Data Sources

Two types of wildlife datasets were used in the analysis: police reported crash data where the first harmful event identified a WVC, and carcass removal data that includes geolocation of a wildlife carcass and is used as evidence of WVC.

Police-reported crash data are made when law enforcement responds to a crash. Reported WVCs are identified based on the first harmful event being contact with a wild animal, which excludes domestic or livestock animals from the crash dataset. The police reports offer detailed insight into the crash circumstances, vehicle and driver information, and location. However, police reports tend to underrepresent the frequency of WVCs. Incidents involving minor vehicle damage are often not reported to police, or if there is a response, the damage may not meet reporting thresholds. This type of non-reporting leads to data gaps and a bias toward more severe collisions. Furthermore, police reports rarely include ecological specifics such as animal species or behavior, which limits the usefulness in wildlife conservation analysis.

Carcass removal data were collected by agencies tasked with clearing wildlife carcasses from roadways. This data may capture events missed by police reports, offering additional spatial and ecological context, such as the frequency and distribution of species killed. However, carcass data are also incomplete. If an animal survives the crash or wanders off and dies elsewhere, it won't be accounted for. Similarly, carcasses may be removed or eaten by other animals before being logged. These limitations highlight that both data sets are imperfect and often fail to account for the full spectrum of wildlife incidents.

Integrating police reports and carcass data sources improves the accuracy and completeness of WVC analyses (Ahmed et al., 2022). Combining police and carcass data allows researchers to identify reporting overlaps, estimate CMFs more reliably, and model crash patterns with greater precision. When police reports and carcass data are used together, the analysis provides a more holistic understanding of collision risk, ecological impact, and the effectiveness of mitigation strategies like wildlife-fencing and crossing structures.

3.5. Segmentation for treatment and control locations

Wildlife-fencing segments were first identified in ArcGIS using the best available GIS layers from each study state. Because the structure, format, and completeness of source files varied substantially across states, the data preparation process required state-specific methods for consistency in the final dataset.

Once the initial fence segments were mapped, Google Street View was used extensively to validate and refine the spatial accuracy of these features. Each fence line was reviewed along its entire length to confirm the presence of fencing, identify discontinuities, and locate all forms of wildlife crossing infrastructure. This included underpasses, overpasses, large drainage structures used by wildlife, and any other features that functioned as potential crossing points. Street View imagery often revealed additional details, and additional attributes were recorded during the review, such as the presence of escape ramps, jump-outs, or other mitigation features. When discrepancies were found between the provided spatial data and the most recent imagery, segment boundaries were adjusted to reflect on-the-ground conditions as accurately as possible.

To accurately represent these features in the GIS, the fence line layer was manually split at every verified crossing location. The Modify and Split tools in ArcGIS were used to divide the line features wherever a crossing occurred or where fencing was interrupted by interchanges, bridges, driveways, or other breaks in continuity. Each resulting segment represented a uniform condition with respect to fencing and crossing opportunities.

The final treatment segments were therefore defined as the stretches of roadway between consecutive wildlife crossings or between points where fencing began or ended. This standardized segmentation process allowed for consistent comparison across states despite differences in their original data sources and documentation. Figure 3-2 shows the Street View of a fence segment and examples of animal crossings along that fence segment.

Figure 3-2 Example animal crossings along study segments

3.5.1. Study Location Identification for Utah

Historic UDOT projects were reviewed using keywords such as wildlife-fencing, fence, fencing, and wildlife to identify projects with wildlife-fencing. The search yielded 29 wildlife specific projects, while a broader search identified 53 projects that included wildlife-fencing with other infrastructure.

Study locations were gathered from the project listings, and milepost information was used to pinpoint fence installation areas. To verify and supplement project details, Google Street View was used to confirm the presence of fences and identify fencing not documented in the project records. Installation dates of wildlife-fences were collected from two sources: 28 projects were confirmed by UDOT project managers, and the remaining dates were determined using historical Google Street View imagery. The latest Google Street View image showing the presence of wildlife-fencing and the earliest available image showing its absence were manually identified using historical imagery. For example, if fencing was visible in November 2017 and all images back to 2014 also showed the fence, but the October 2012 image showed no fencing, it was concluded that installation occurred in 2013. That year was then assumed to be the installation date and used to define the "before" and "after" periods. In cases where historical imagery was missing for certain years, those years were excluded from the study. For instance, if images from 2014 to 2018 were unavailable, but the 2019 image showed fencing and the 2013 image showed no fencing, the "before" period was defined as 2011–2013 and the "after" period as 2020–2023. Installation timelines spanned from 2011 to 2023. This combination of official records, visual confirmation, and direct input from UDOT personnel provided the dataset for evaluating the effectiveness of wildlife-fencing projects statewide. Locations were excluded when a fence had been installed before 2009, as crash data earlier than 2009 was not available. A 300-foot buffer was used to assign WVCs to roadway segments.

Roadways were divided into segments using Google Street View to identify locations where animals could potentially cross, shown in Figure 3-5 Aerial view of an animal crossingFigure 3-3. The top and middle images show an example of wildlife-fencing in Utah, and the bottom image shows the specification of Type G fencing which is used as wildlife-fencing in Utah. A study segment was identified between an available wildlife crossing such as a culvert, bridge, or interchange. The study segments also stopped at fence terminations and were noted as a fence end. Segments shorter than 0.5 miles were merged with the closest adjacent segment for consistency.

I-15 accounted for the largest share, with 43% of all reported wildlife crashes. US-6 and SR-73 followed with 10% and 9%, respectively, identifying that these routes also experience frequent animal crossings. US-40 and I-80 each contributed 6%, while US-91 made up 5%. Other routes like US-189 and US-89 each represented 4%, and smaller shares were seen on US-89/91 (2%), I-70 (1%), and I-84 (1%). This breakdown helps identify priority areas for wildlife mitigation efforts, especially along I-15 and other high-impact corridors.

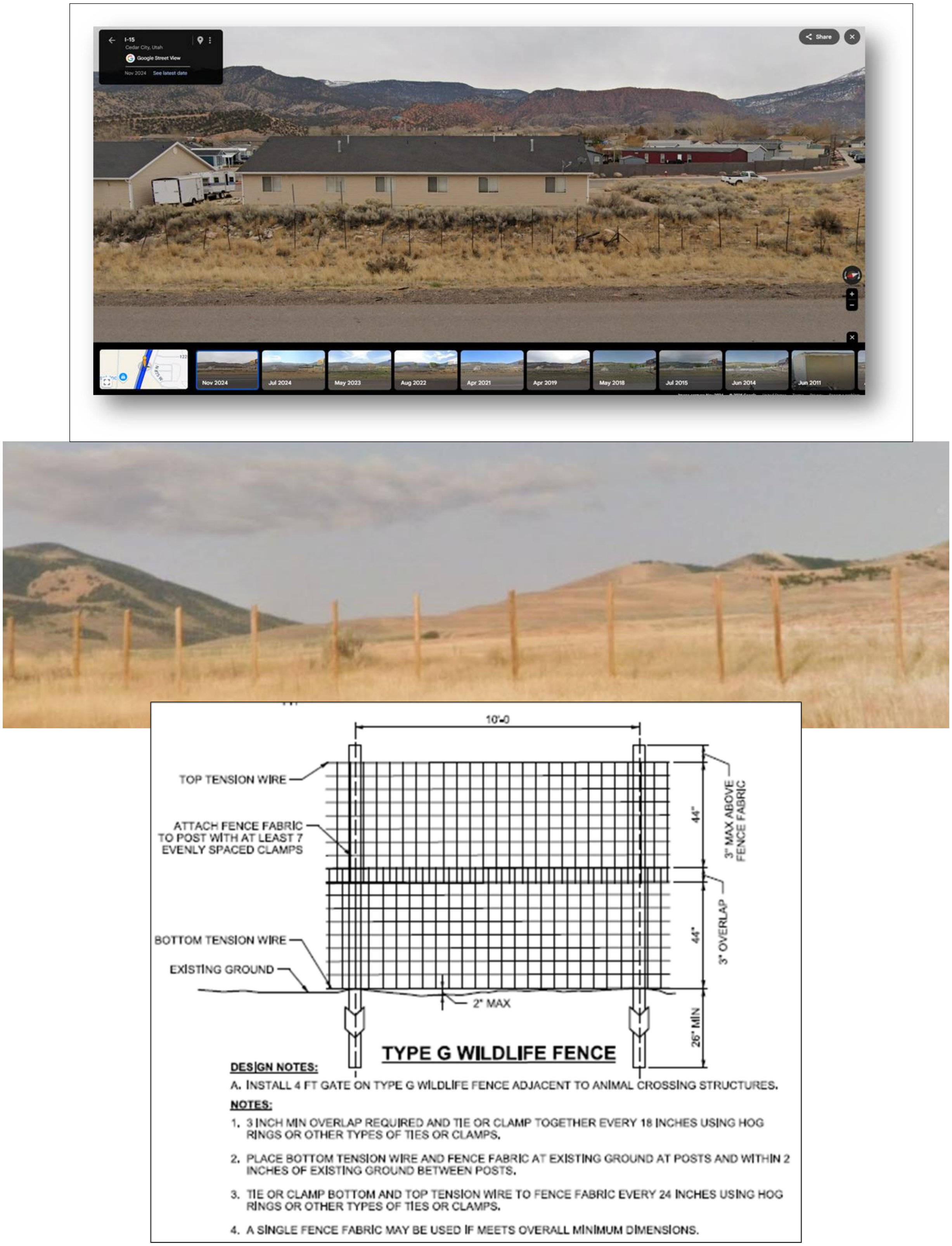


Figure 3-3 Identifying wildlife-fencing installations

3.5.2. Study Location Identification for Colorado

Wildlife-fencing locations in Colorado were identified using a combination of spatial datasets, mileposts information, and publicly available transportation information, including traffic volumes, crash records, and carcass data. A review of these datasets, along with project documentation, identified 50 projects statewide that included wildlife-fencing installations. The study focused on roadway segments where fencing was installed in 2010 or later, ensuring consistency with the availability and reliability of traffic and safety data used in subsequent analyses. Figure 3-4 illustrates the milepost information and location of the wildlife crossings as displayed within a GIS interface.

Study locations were delineated using documented fence start (FncStart) and fence end (FncEnd) information in combination with roadway spatial reference data from the wildlife crossing dataset. Each wildlife-fenced segment was attributed with the structure build year (StrBuildYr), which was used to define the "before" and "after" analysis periods. The *before* period represents the years prior to fence installation and captures the number of WVCs occurring without wildlife-fencing, while the *after* period represents the years following installation and reflects crash occurrence with wildlife-fencing in place. This before-and-after framework was used to evaluate changes in crash frequency associated with the installation of wildlife-fencing.

To more accurately represent potential wildlife movement spatial consistency in the analysis, wildlife-fenced segments were further subdivided at locations where animals could reasonably cross- the roadway. Wildlife crossings including culverts, underpasses, bridges, interchanges, and other structures were identified through a review of Google Street View imagery and spatial reference data. Fence segments were then divided at these locations to create continuous segments bounded by adjacent crossings or fence endpoints. Each roadway segment represented a uniform opportunity for wildlife passage, supporting more precise assignment of traffic and safety attributes. Figure 3-5 shows an example of an animal crossing where the fence segment was divided.

Traffic data (AADT)were obtained from the Colorado DOT (CDOT) open-source data portal for the years 2010 through 2024. These datasets were consolidated into a single traffic database using CountStationID as the primary key. AADT values were then assigned to each roadway segment based on spatial proximity to traffic count stations, generally within a 250 feet distance threshold. For segments without a nearby station, AADT values were manually assigned using the closest appropriate count location and roadway characteristics. Using the structure build year, average AADT values were calculated for both the *before* and *after* periods of each fence installation, allowing traffic exposure to be incorporated into subsequent evaluations of fencing effectiveness.

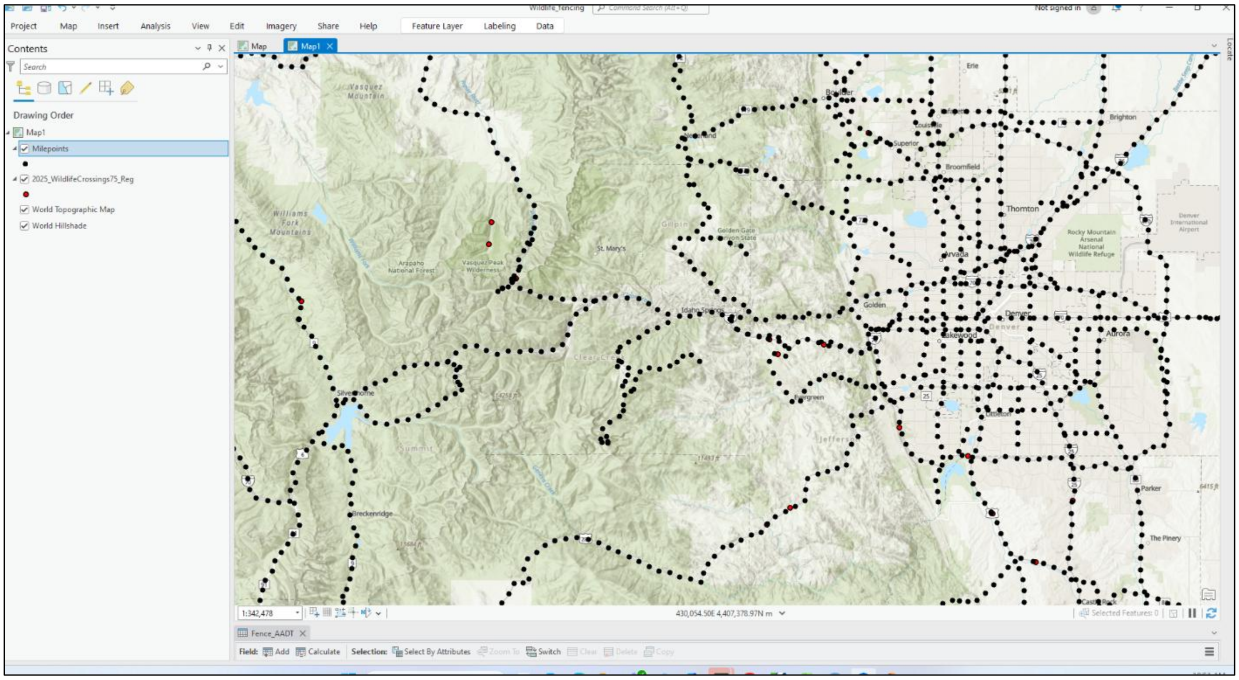


Figure 3-4 Location of milepost and animal crossings

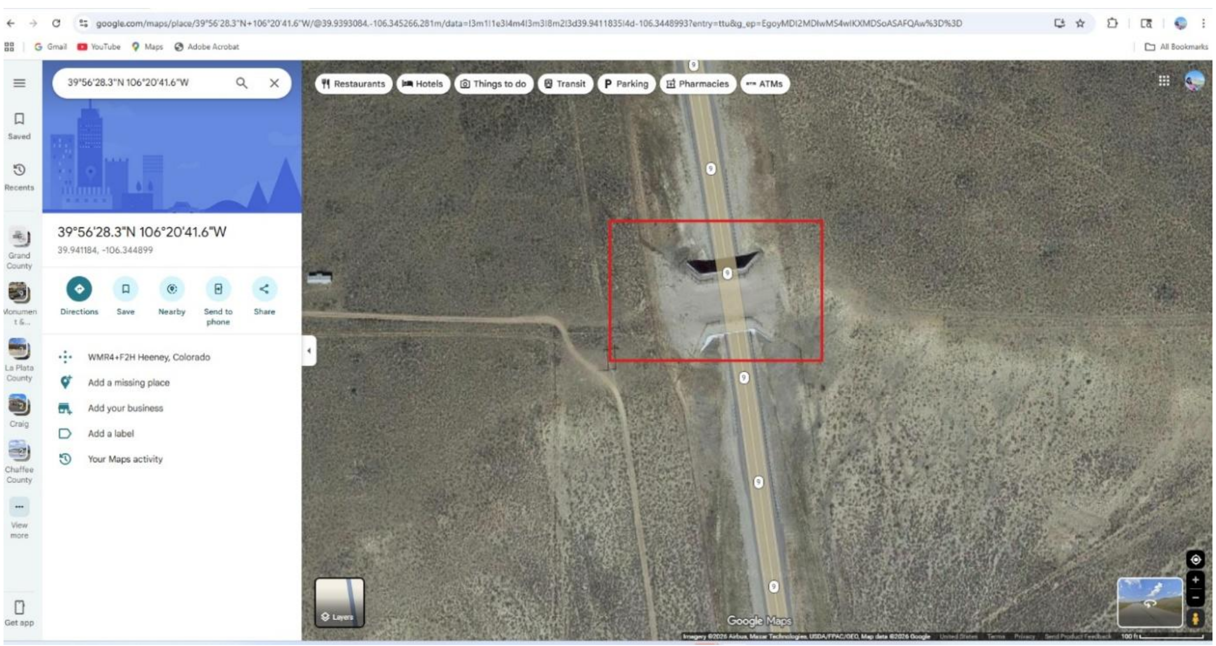


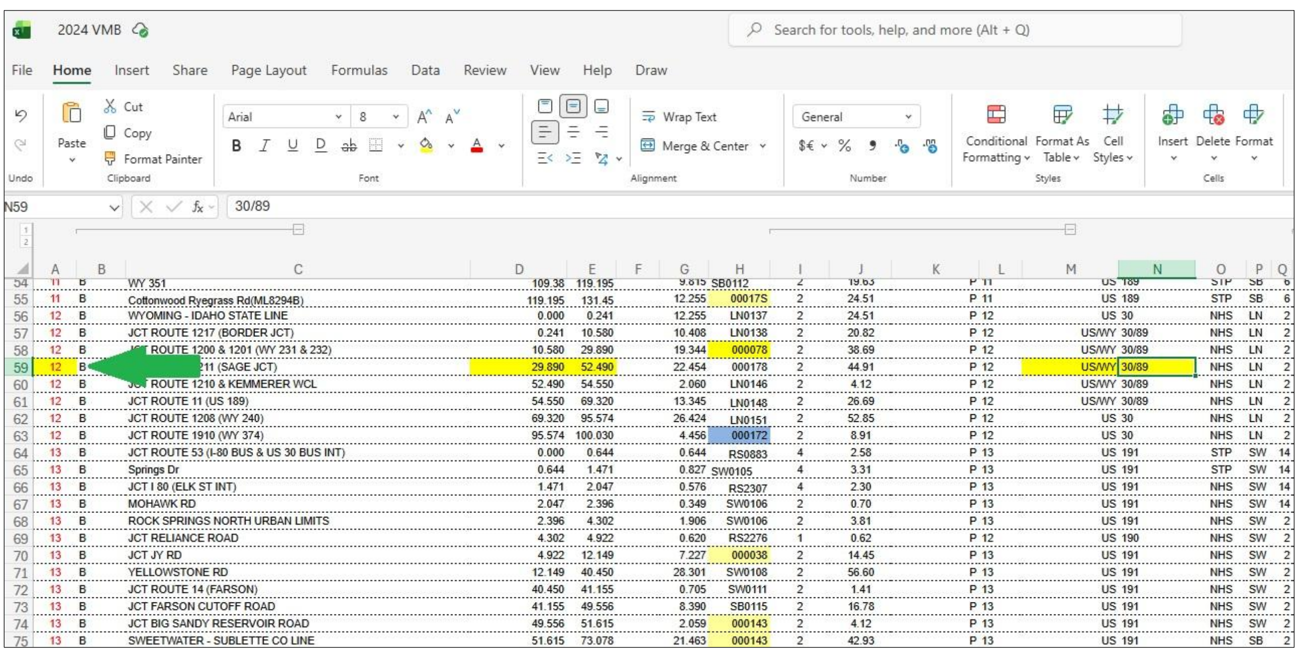
Figure 3-5 Aerial view of an animal crossing

3.5.3. Study Location Identification for Wyoming

The exclusionary wildlife-fencing data and AADT data having corresponding mileposts for the beginning and end of the fence sections were obtained from WYDOT. Main Line (ML)/Route numbers are included in both the AADT and fencing spreadsheets.

The route information in the GIS roadway layer provided by WYDOT was matched to the route numbers provided in the AADT spreadsheet, shown in Figure 3-6. In the GIS dataset, route identifiers were displayed with an "ML" prefix (e.g., ML12B). For the purpose of linking datasets, the "ML" prefix was disregarded, and the numeric portion of the identifier was used to locate the corresponding entry in the AADT table. As an example, the Nugget Canyon segment along US-30, one of the exclusionary fencing sections included in the study, was matched using this approach. In the AADT dataset, US-30 was listed as Route 12, and the same roadway appeared in the GIS layer as ML12B. The suffix "B" was used to indicate that the segment represented both directions of a two-lane highway. For divided four-lane highways, suffixes "I" and "D" were used to denote the direction in which mileposts increased ("I") or decreased ("D"). To complete the matching process, the numeric route value (e.g., 12) was used to identify the correct row in the AADT spreadsheet shown in **Error! Reference source not found.**. The appropriate roadway section was then confirmed by comparing the milepost range in the GIS segment and the AADT record. The screenshot highlights the correct AADT row for the Nugget Canyon segment on US-30 (Route 12).

Through this process, consistent alignment between GIS roadway segments and AADT attributes was achieved across all study corridors. Figure 3-7 shows Wyoming segmentation methodology.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
54	11	B	WY 351	109.38	119.195		9.815	SB0112	2	19.63		P 11	US	189	STP	SB	6
55	11	B	Cottonwood Ryegrass Rd(ML8294B)	119.195	131.45		12.255	00017S	2	24.51		P 11	US	189	STP	SB	6
56	12	B	WYOMING - IDAHO STATE LINE	0.000	0.241		12.255	LN0137	2	24.51		P 12	US	30	NHS	LN	2
57	12	B	JCT ROUTE 1217 (BORDER JCT)	0.241	10.580		10.408	LN0138	2	20.82		P 12	US/WY	30/89	NHS	LN	2
58	12	B	… ROUTE 1200 & 1201 (WY 231 & 232)	10.580	29.890		19.344	000078	2	38.69		P 12	US/WY	30/89	NHS	LN	2
59	12	B	…211 (SAGE JCT)	29.890	52.490		22.454	000178	2	44.91		P 12	US/WY	30/89	NHS	LN	2
60	12	B	… ROUTE 1210 & KEMMERER WCL	52.490	54.550		2.060	LN0146	2	4.12		P 12	US/WY	30/89	NHS	LN	2
61	12	B	JCT ROUTE 11 (US 189)	54.550	69.320		13.345	LN0148	2	26.69		P 12	US/WY	30/89	NHS	LN	2
62	12	B	JCT ROUTE 1208 (WY 240)	69.320	95.574		26.424	LN0151	2	52.85		P 12	US	30	NHS	LN	2
63	12	B	JCT ROUTE 1910 (WY 374)	95.574	100.030		4.456	000172	2	8.91		P 12	US	30	NHS	LN	2
64	13	B	JCT ROUTE 53 (I-80 BUS & US 30 BUS INT)	0.000	0.644		0.644	RS0883	4	2.58		P 13	US	191	STP	SW	14
65	13	B	Springs Dr	0.644	1.471		0.827	SW0105	4	3.31		P 13	US	191	STP	SW	14
66	13	B	JCT I 80 (ELK ST INT)	1.471	2.047		0.576	RS2307	4	2.30		P 13	US	191	NHS	SW	14
67	13	B	MOHAWK RD	2.047	2.396		0.349	SW0106	2	0.70		P 13	US	191	NHS	SW	14
68	13	B	ROCK SPRINGS NORTH URBAN LIMITS	2.396	4.302		1.906	SW0106	2	3.81		P 13	US	191	NHS	SW	2
69	13	B	JCT RELIANCE ROAD	4.302	4.922		0.620	RS2276	1	0.62		P 12	US	190	NHS	SW	2
70	13	B	JCT JY RD	4.922	12.149		7.227	000038	2	14.45		P 13	US	191	NHS	SW	2
71	13	B	YELLOWSTONE RD	12.149	40.450		28.301	SW0108	2	56.60		P 13	US	191	NHS	SW	2
72	13	B	JCT ROUTE 14 (FARSON)	40.450	41.155		0.705	SW0111	2	1.41		P 13	US	191	NHS	SW	2
73	13	B	JCT FARSON CUTOFF ROAD	41.155	49.556		8.390	SB0115	2	16.78		P 13	US	191	NHS	SW	2
74	13	B	JCT BIG SANDY RESERVOIR ROAD	49.556	51.615		2.059	000143	2	4.12		P 13	US	191	NHS	SW	2
75	13	B	SWEETWATER - SUBLETTE CO LINE	51.615	73.078		21.463	000143	2	42.93		P 13	US	191	NHS	SB	2

Figure 3-6 AADT data format for Wyoming

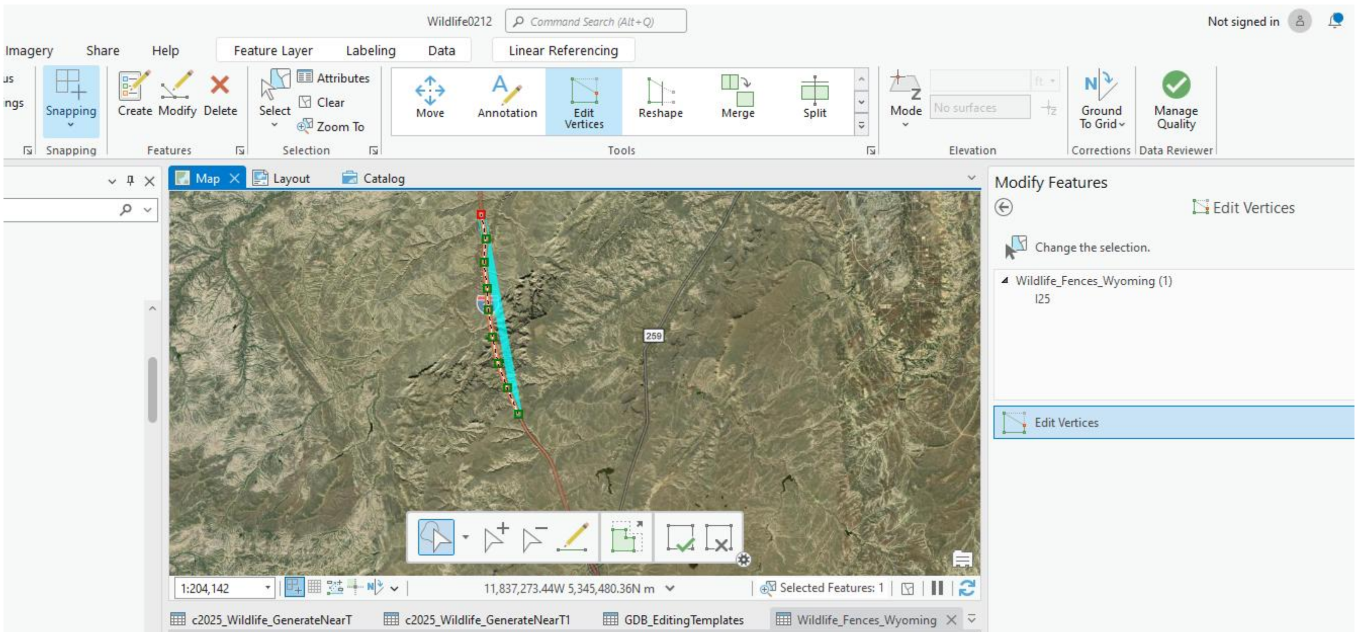


Figure 3-7 Wyoming segmentation methodology

3.5.4. Study Location Identification for Idaho

The Idaho Transportation Department (ITD) provided detailed station-based segment data for US-30 in both the eastbound and westbound directions, including start and end stations, segment lengths, removal lengths, and cumulative totals. The dataset identified 14 priority segments, each classified as Type 8 fence, with lengths that ranged from approximately 860 feet to more than 5,800 feet. For each priority section, ITD supplied paired measurements for the eastbound and westbound lanes, which allowed for direct comparison of existing and removal lengths. The cumulative totals increased from roughly 4,300 feet at Priority 1 to more than 40,000 feet by Priority 14, offering a continuous representation of the corridor. This structured dataset supported consistent evaluation of segment-level conditions, informed project scoping, and provided a reliable foundation for subsequent engineering analysis. In addition, ITD supplied comprehensive records of wildlife-fencing and crossing infrastructure across multiple districts and highways. These records included installation years, project costs, fence types and heights, and GPS coordinates for undercrossings and overcrossings. Notable projects included the SH-21 Cervidae Peak Wildlife Overcrossing, the SH-28 Lemhi Wildlife Undercrossing system, and the I-90 Osburn Wildlife Overcrossing, with fencing lengths ranging from 0.1 to over 3 miles. An ArcGIS layer for Idaho mile points was also provided along with fence data in an ArcGIS layer. This layer also provided installation data for the Idaho fence segments. Datasets provided in Excel format and ArcGIS layers were used to finalize the final fence segments. This layer was checked against Google Street View for start and end mile posts for projects. ITD also provided crash and carcass data in GIS layers along with urban boundaries.

3.5.5. Study Location Identification for Nevada

NDOT provided a comprehensive set of materials to support this study. The state submitted detailed information for all known wildlife-fencing and crossing projects. NDOT also supplied a map of project locations corresponding to each spreadsheet tab, along with two GIS shapefiles: one representing the centerpoints of wildlife crossing structures and another delineating fencing limits based on roadway centerlines. In addition, NDOT shared a legislative writeup prepared in 2023, of which the second page included a detailed cost breakdown for the Verdi Wildlife-fencing Project, the most recent installation completed at the end of 2023. NDOT further explained its lump sum contracting process, noting that wildlife-related components were typically embedded within larger construction projects, making it difficult to isolate fencing costs unless a contractor provided a special breakdown.

NDOT reported that wildlife-mitigation costs vary widely across past projects due to differences in infrastructure type, materials, terrain, geology, workforce, supply chain, and economic conditions. NDOT's Inventory of Wildlife Connectivity Needs documents this variation using historical project data. Although earlier projects were relatively affordable, construction costs have risen approximately 68% since 2020 making new projects significantly more expensive. NDOT's most recent major structures included two wildlife overpasses on I-80 in Elko County (constructed in 2018 at $10 million each) and a large underpass on SR-160 in Clark County (constructed in 2020 at $1.5 million). Current estimates place these structures at roughly $17 million per overpass and $2.5 million per underpass.

The most recent wildlife-fencing project, completed in late 2023 near Verdi along I-80, cost approximately $5.35 million and included 5.75 miles of 8 feet fencing, escape ramps, and cattle guards at every interchange equating to roughly $930,000 per mile. NDOT developed a new statewide prioritization that integrates updated WVC data and ecological variables as of April 2025. Although more than 90 segments were initially identified by partners, this process narrowed the list to the top 30 priority locations, five of which have already been completed or require only minor work. Addressing the remaining 25 locations would require 276 miles of fencing, 25 overpasses, and 14 underpasses, with a minimum estimated cost of $719.2 million, not including species-specific mitigation (e.g., desert tortoise) or livestock-related needs.

NDOT also noted several high-priority, species-specific projects outside the top 30 list. For example, the I80 Dunphy Hills/Humboldt River project currently in design and scheduled for 2026 includes five miles of fencing at an estimated $4.65 million. Another project on US395 north of Reno, addressing a hotspot for deer, elk, and bear collisions, would require nine miles of fencing, two underpasses, and one overpass at an estimated $30.4 million. All cost estimates provided by NDOT were based on a high-level desk review and have not yet been refined through detailed design or engineering.

Figure 3-8 displays the compiled wildlife-fencing layers for the five study states: Idaho, Nevada, Utah, Wyoming, and Colorado. Each state's fencing dataset is represented as a separate GIS layer, allowing the spatial distribution of exclusionary and wildlife-friendly fencing to be viewed and analyzed across the region. These layers form the foundation for identifying treatment segments, evaluating fencing continuity, and linking fencing to crashes, carcasses, and habitat datasets. By maintaining separate layers for each state, the analysis accommodates differences in data sources, mapping standards, and mitigation practices while enabling regional comparisons.

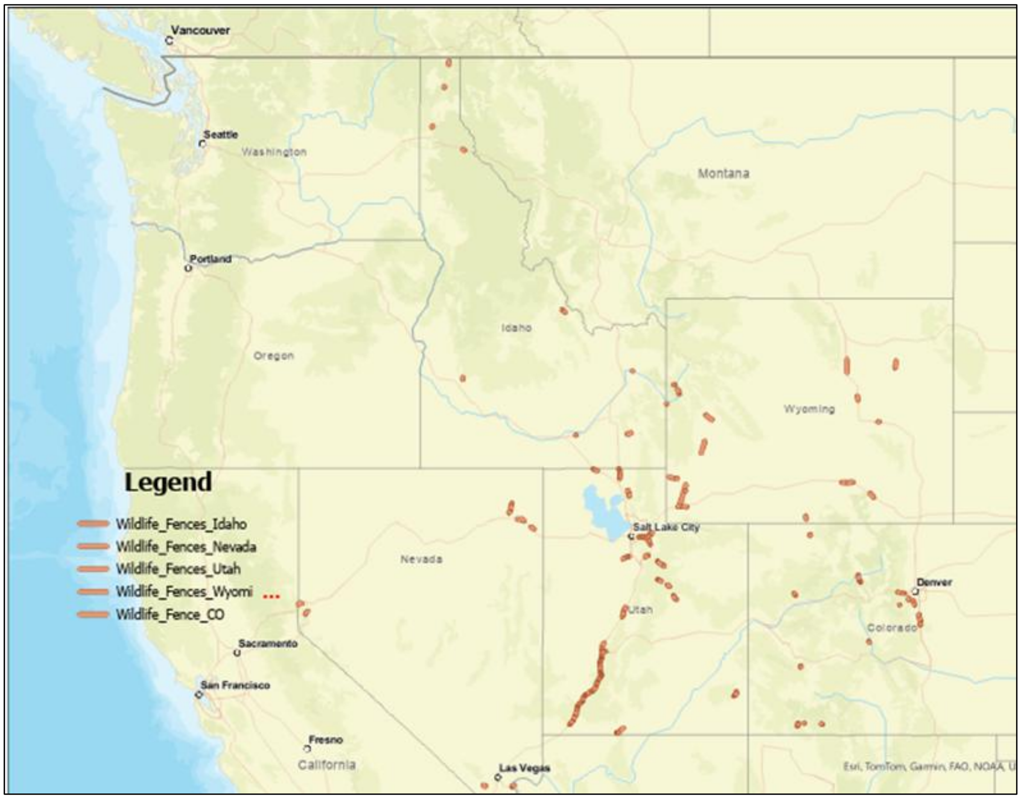


Figure 3-8 Segments from all study locations

3.6. Control Data Selection

Control segments were selected based on how closely they matched treatment segments, especially in terms of roadway conditions and history of wildlife collisions. Wherever possible, control sites were placed near the treatment segments and included areas where animal crossings were likely to occur. For example, speed limits for treatment segments range between 35 mph and 80 mph with mean speed limit of 69 mph, and speed limits for control segments ranged from 30 mph to 80 mph with mean speed limit of 58 mph. Both treatment and control segments were mapped using ArcGIS. Maps for treatment and control locations for each state are shown in Figure 3-9 (Colorado), Figure 3-10 (Wyoming), Figure 3-11 (Idaho), and Figure 3-12 (Utah). An overview of all treatment and control locations in Colorado, Wyoming, and Utah is shown in Figure 3-13.

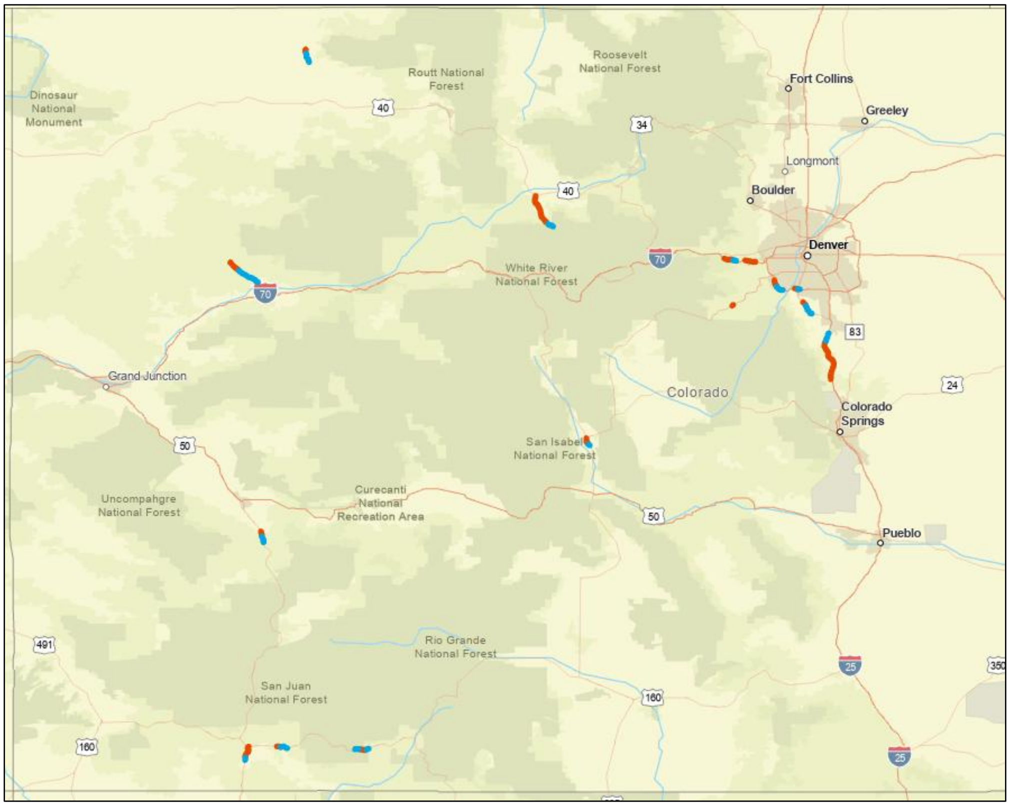


Figure 3-9 Colorado treatment and control sites

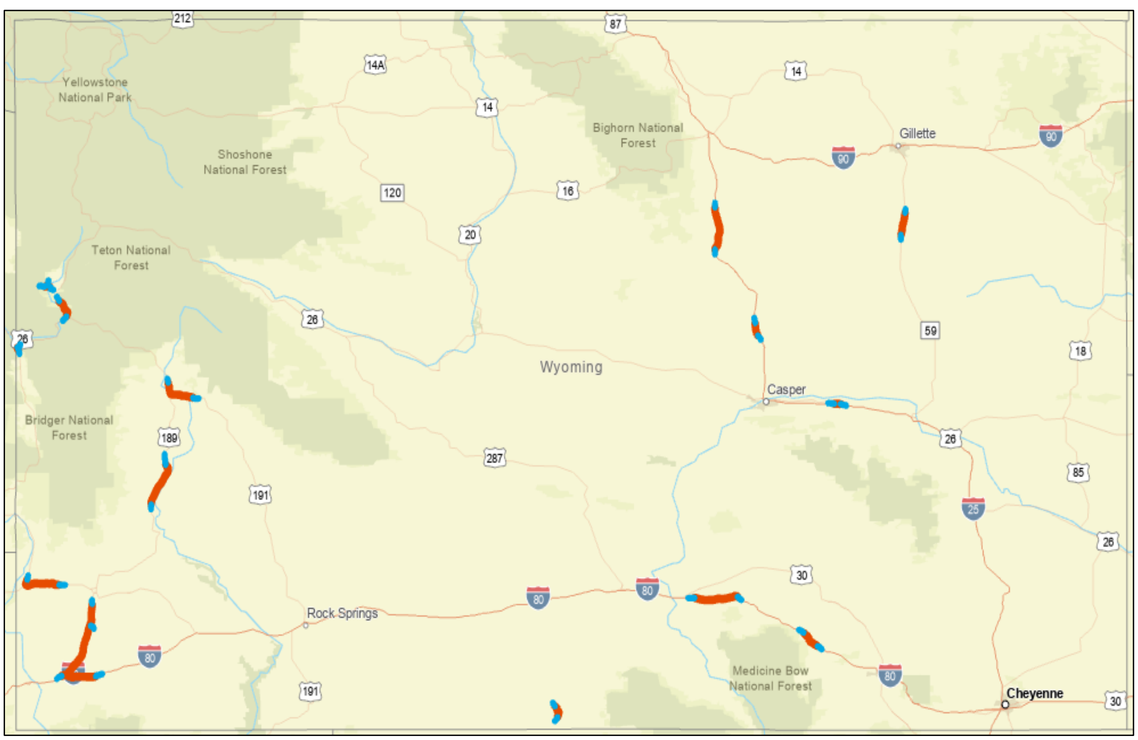


Figure 3-10 Wyoming treatment and control sites

Figure 3-11 Idaho treatment and control sites

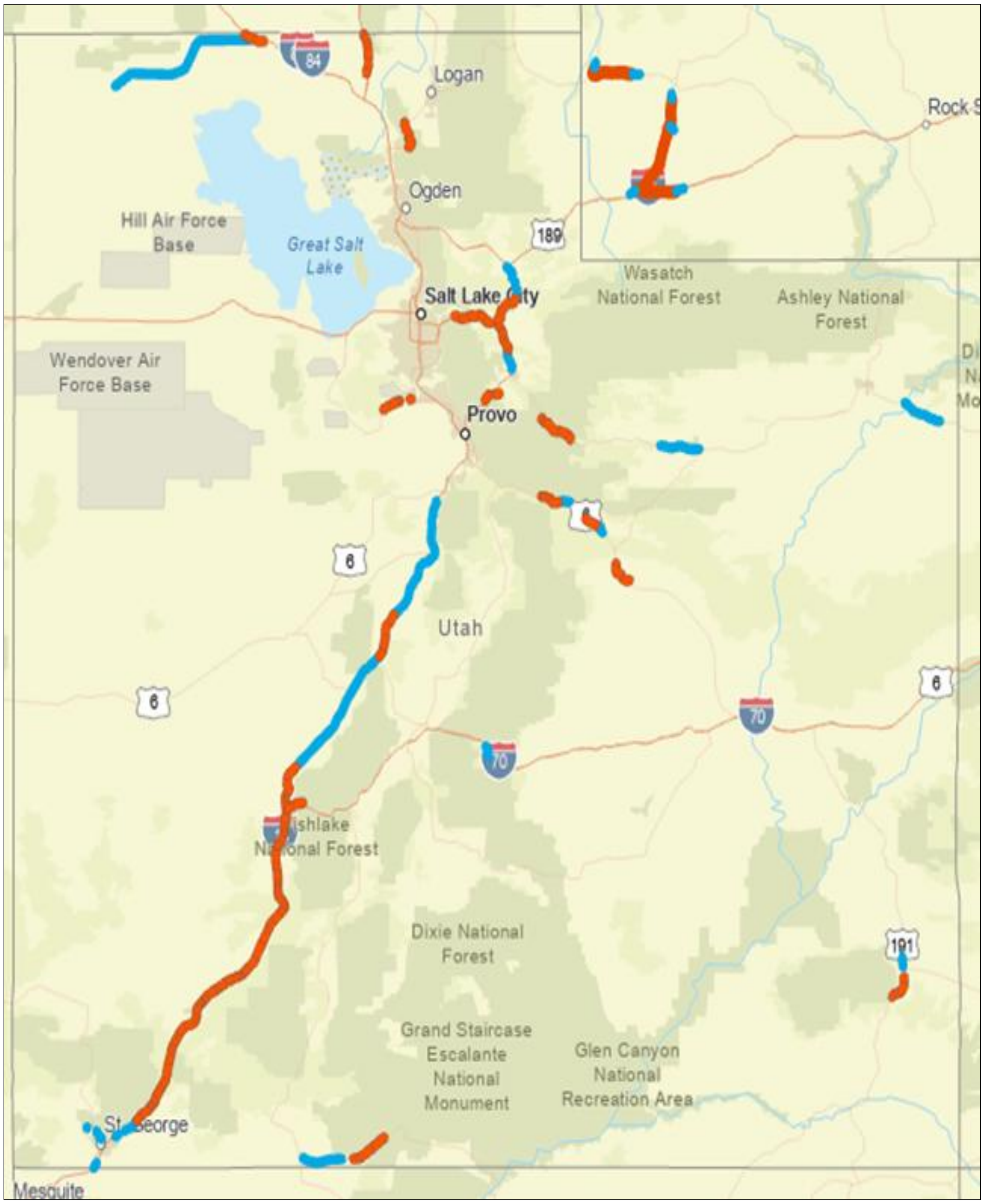


Figure 3-12 Utah treatment and control sites

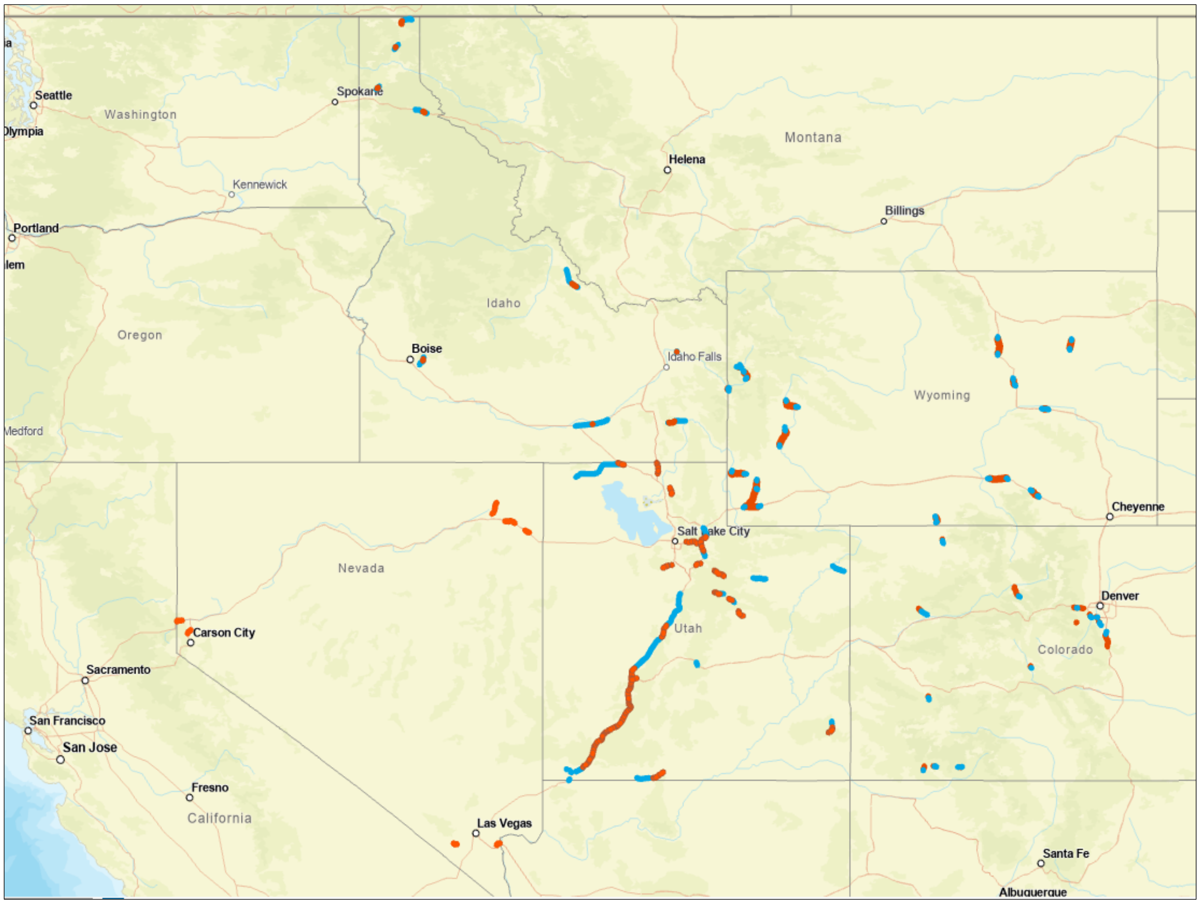


Figure 3-13 All treatment and control segments

3.7. Reported Crash Data

WVC and carcass data from the DOTs were obtained from 2010 to 2024. Domestic animal crashes were excluded from the study. Crash data was processed to develop a consistent, segment-level dataset for evaluating WVC patterns across treatment and control road segments. The workflow integrated multiple data sources including statewide crash records, wildlife-related crash classifications, roadway segmentation, and treatment installation timelines to produce a structured dataset suitable for before-and--after analysis and statistical modeling. Each step was designed to create a clear linkage between crash events and roadway segments, classify crashes by treatment period, and generate summary metrics that support evaluation of mitigation effectiveness. The following subsections describe the data processing steps in detail.

Added Crash Data to Treatment Segments

- Crash records were integrated with the treatment segment layer by performing a spatial join between the crash dataset and the segmented roadway network. This step linked each crash point to the corresponding treatment segment based on geographic location, creating a unified dataset for subsequent analysis.

Extracted Crash Records for All Treatment Segments

- All crash events falling within the spatial extent of treatment segments were extracted. This involved filtering the statewide crash dataset to retain only those records intersecting the treatment geometry. The resulting subset represented the complete crash history relevant to the fenced or mitigated roadway sections.

Filtered by WVC Type

- The extracted crash records were further refined by selecting only WVCs. This filtering step used the crash type or contributing factor fields (e.g., "WILD ANIMAL") to isolate WVCs. The filtered dataset formed the basis for WVC analysis.

Assigned Crashes to Pre- and Post-Treatment Periods

- Each WVC was assigned to either the pre-treatment or post-treatment period based on the crash date and the documented installation year of the mitigation (e.g., fencing or crossing structures). This temporal classification allowed for comparison of WVC patterns before and after treatment implementation.

Added Total Before/After Crashes to Treatment Segments

- Segment-level summaries were created by aggregating the number of WVCs occurring in the pre-treatment and post-treatment periods. These totals were appended as new attributes to each treatment segment, providing a clear representation of collision frequency over time.

Summarized Total WVCs for Pre-Treatment Years

- For each treatment segment, all WVCs occurring prior to the installation year were summed to produce a pre-treatment WVC count. This summary metric served as a baseline for evaluating mitigation effectiveness.

Summarized Total WVCs for Post-Treatment Years

- Similarly, all WVCs occurring after the installation year were summed to generate a post-treatment WVC count. This metric captured the collision frequency under treated conditions.

Added Severity-Specific Counts (KABC, PDO)

- Crash severity information was incorporated by calculating the number of WVCs in each severity category (e.g., K, A, B, C, and PDO). These severity-specific counts were added to the treatment dataset to support more detailed safety assessments and modeling.

Crash Data Processing for Control Segments

- Added Crash Data to Control Segments
- A spatial join was performed between the crash dataset and the control segment layer to associate each crash with its corresponding control segment. This step created a parallel dataset for comparison with treatment segments.
- Extracted WVCs for All Control Segments

- WVCs were extracted for all control segments using the same filtering criteria applied to the treatment dataset. This produced a consistent set of WVC records for untreated roadway sections.

Extracted Severity-Specific Counts (Total, KABC, PDO)

- For each control segment, total WVCs and severity-specific counts were calculated. These metrics were added as attributes to the control dataset to support statistical modeling and comparison with treatment segments.

Prepared Final Control Dataset for Statistical Modeling

- The control dataset was finalized by standardizing attribute fields, verifying temporal coverage, and organizing the data into a format suitable for modeling. This included aligning the control dataset structure with the treatment dataset to support paired or comparative analyses.

3.8. Reported Carcass Data

Carcass data for Utah, Idaho, Wyoming, and Colorado are described in the following subsections. NDOT was not able to provide carcass data for Nevada.

3.8.1. Utah Carcass Data

Carcass data was obtained from UDOT for the years 2010 to 2024. Figure 3-14 compares data points between police reported crash data (left) and carcass data (right). Table 3-1 provides the carcass count by animal type, highlighting the species most frequently involved in WVCs. Mule deer dominate the list, with 101,661 carcasses (91%), underscoring their vulnerability and prevalence across the state's highways. Elk (3,010 at 2.7%) and northern raccoons (2,342 at 2.1%) follow as the next most common species. A wide range of other wildlife including moose, pronghorn antelope, coyotes, and skunks also appear in significant numbers but at low overall percentage of carcasses.

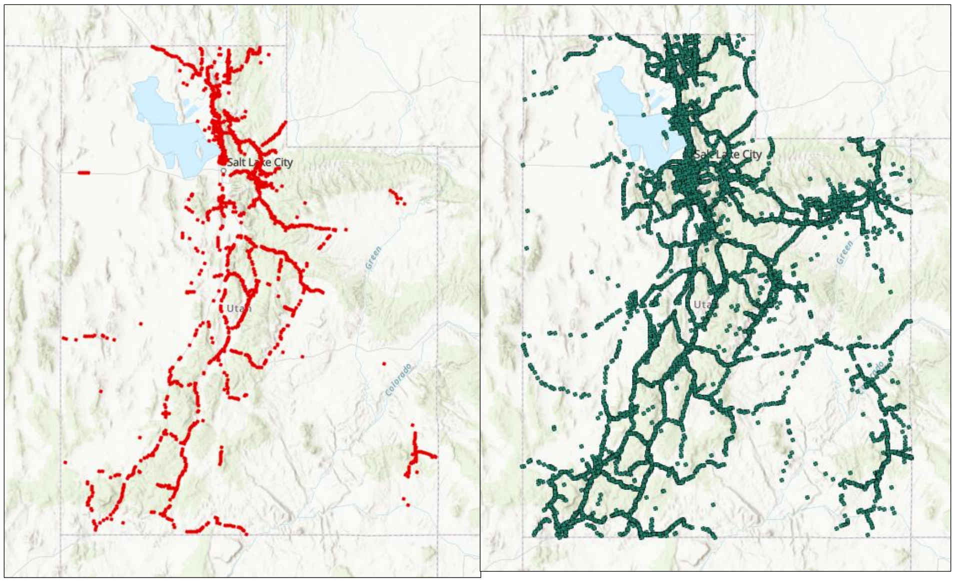


Figure 3-14 Utah comparison of crash data (left) and carcass data (right)

Table 3-1 2010-2024 Carcass Count

Animal Type	Carcass Count	Animal Type	Carcass Count
Mule Deer	101,661	Gray Fox	46
Elk	3,010	Jackrabbit	36
Northern Raccoon	2,342	Bobcat	34
Others and Unknown	764	Utah Prairie Dog	34
Domestic Cat	541	Muskrat	26
Pronghorn Antelope	487	Domestic Sheep	23
Moose	456	Black Bear	22
Striped Skunk	445	Golden Eagle	22
Domestic Dog	257	Great Horned Owl	19
Porcupine	256	Turkey Vulture	18
Coyote	245	Mojave Desert Tortoise	17
American Badger	239	Canada Goose	15
Red Fox	148	Ground Squirrel	15
Domestic Cow	122	Ring-necked Pheasant	14
Beaver	84	Greater Sage-Grouse	12
Cougar (Mountain Lion)	79	Domestic Horse	11
Kit Fox	77	Red-tailed Hawk	11
Bighorn Sheep	49	Bison	10

Utah saw a consistent gap between reported WVCs and the number of carcasses removed each year, shown in Table 3-2. Carcass data far exceeded reported WVCs, with differences ranging from 2,100 to over 4,500. On average, carcass counts were 50 to 60% higher than crash counts, indicating many incidents go unreported, especially if there are no human injuries. Figure 3-15 shows the yearly percentage difference between WVCs and carcass data. The negative trend line indicates the difference is reducing year over year.

Table 3-2 Reported WVCs to Carcass Count by Year 2010-2024

Year	Crash Count	Carcass Count	Difference	% Diff
2010	2,342	6,345	4,003	63.1
2011	2,279	4,889	2,610	53.4
2012	2,476	5,680	3,204	56.4
2013	2,615	7,196	4,581	63.7
2014	2,673	6,049	3,376	55.8
2015	3,116	6,936	3,820	55.1
2016	3,044	7,384	4,340	58.8
2017	2,869	6,610	3,741	56.6
2018	2,906	6,982	4,076	58.4
2019	2,832	6,481	3,649	56.3
2020	2,458	5,268	2,810	53.3
2021	2,391	4,839	2,448	50.6
2022	2,553	5,320	2,767	52.0
2023	2,492	4,603	2,111	45.9
2024	2,204	4,683	2,479	52.9

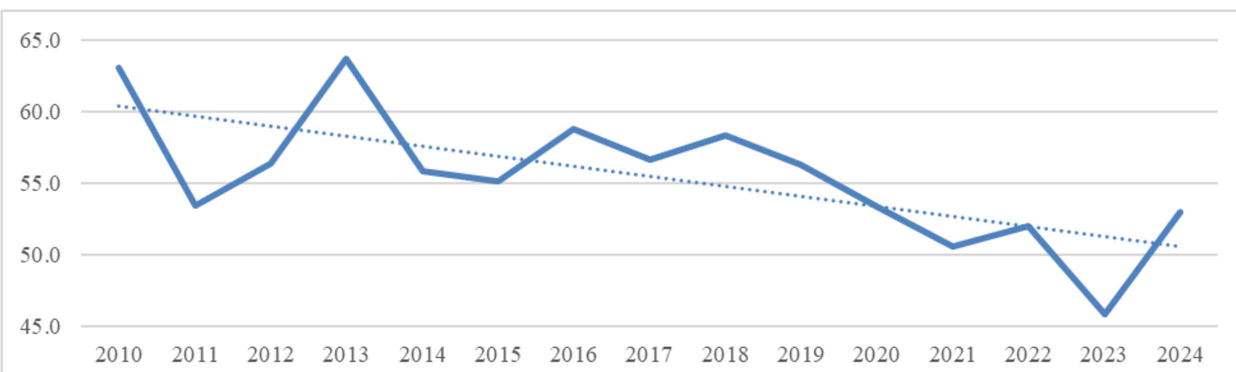


Figure 3-15 Percent difference in reported WVCs and carcass data by year.

3.8.2. Idaho Carcass Data

Carcass data was obtained from ITD for the years 2010 to 2024. Figure 3-16 compares data points between police reported crash data (left) and carcass data (right). Table 3-3 summarizes the difference between reported crashes and carcass counts from the year 2011-2023, allowing for carcass data to be collected at least 1 year before or after wildlife-fencing installations. The data show a consistent pattern across the 2011–2023 period: carcass counts are substantially higher than reported crash counts, with the difference ranging from 24% to 81%. This gap is expected, as many WVCs do not result in police-reported crashes but still have carcasses that are documented by maintenance crews. However, the magnitude and variability of the difference over time provide important insights into reporting behavior, wildlife activity, and potential underrepresentation of WVCs in crash databases. Across the 2011–2023 period, the data show a consistent pattern in which carcass counts far exceed reported WVC counts, but the magnitude of this gap changes substantially over time, revealing important trends in reporting behavior, wildlife activity, and roadway conditions. In the early years (2011–2015), carcass totals were between 2,300 and 2,900 higher than crash counts each year, representing differences of roughly 68–81%. This indicates that a large share of WVCs was not captured in police-reported crash data likely because many incidents involved only minor vehicle damage, drivers did not stop, or the events did not meet reporting thresholds while carcass collection records captured a broader set of encounters. As shown in Figure 3-16, carcass counts consistently exceeded reported WVC counts throughout the 2011–2023 period.

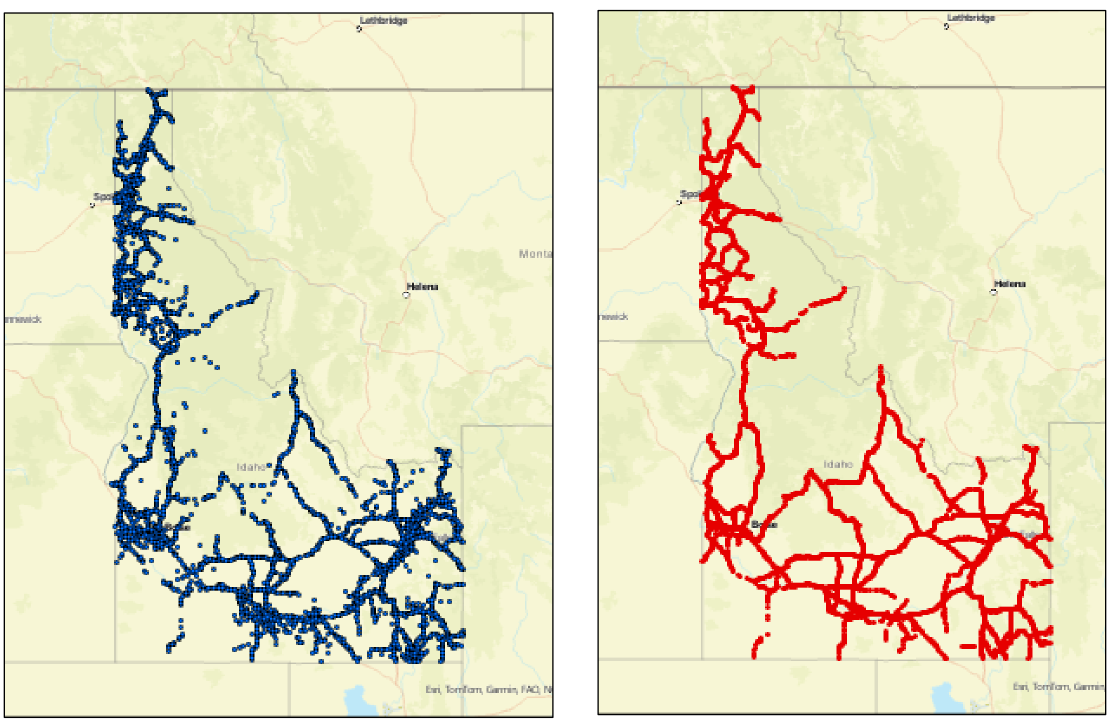


Figure 3-16 Idaho comparison of crash data (left) and carcass data (right)

From 2016 to 2020, the gap narrows, with differences dropping into the 51–65% range, suggesting shifts in wildlife movement patterns, changes in carcass collection practices, or improvements in crash reporting. The most striking change occurs from 2021 onward, where the difference falls sharply to just 24–29%, the lowest levels in the entire dataset. This could reflect several interacting factors, including reduced carcass collection due to staffing or policy changes, increased reporting of WVCs, changes in deer population density, or altered traffic patterns during and after the COVID-19 period. Regardless of the underlying cause, the long-term trend highlights a critical insight: crash data alone substantially underestimates the true frequency of WVCs, and carcass data provides essential supplemental information for identifying hotspots, understanding temporal patterns, and supporting data-driven mitigation planning. The narrowing gap in recent years underscores the importance of examining both datasets together to interpret whether observed changes reflect real safety improvements, shifts in wildlife behavior, or changes in reporting and collection practices.

Table 3-3 Reported WVCs to Carcass Count by Year 2010-2023 for Idaho

Year	Crash Count	Carcass Count	Difference	Percent Diff
2011	1,051	3,447	2,396	70%
2012	617	3,195	2,578	81%
2013	1,086	3,458	2,372	69%
2014	1,103	3,922	2,819	72%
2015	1,402	4,332	2,930	68%
2016	1,394	3,083	1,689	55%
2017	1,278	2,706	1,428	53%
2018	1,191	3,440	2,249	65%
2019	1,435	3,620	2,185	60%
2020	1,332	2,741	1,409	51%
2021	1,616	2,179	563	26%
2022	1,620	2,272	652	29%
2023	1,494	1,972	478	24%

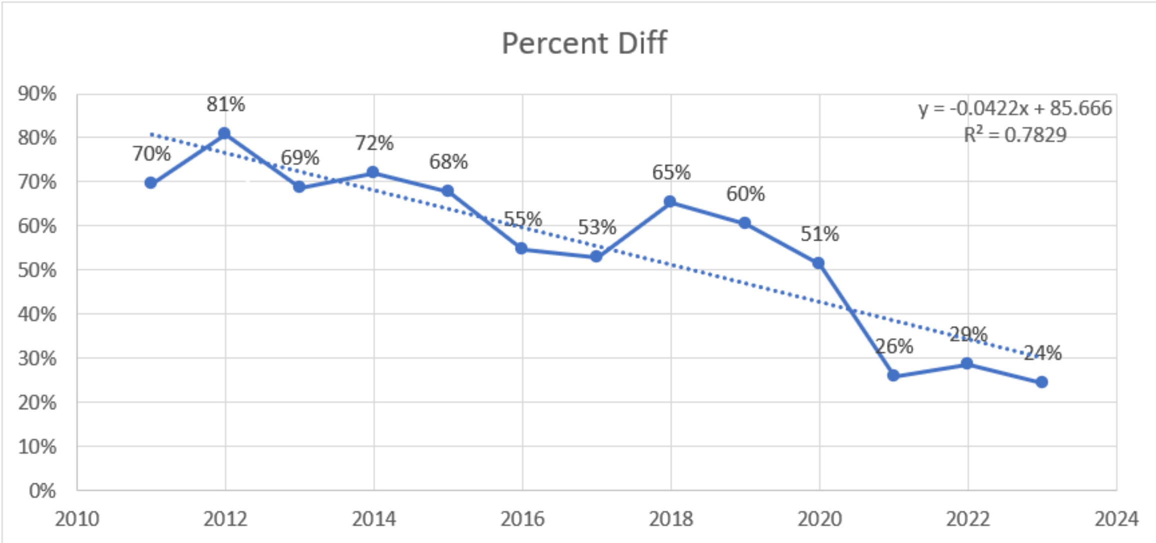


Figure 3-17 Percent difference between carcass counts and reported WVC counts for Idaho

3.8.3. Wyoming Carcass Data

Wyoming provided carcass inventories for the study segments. For example, the carcass inventory for ML10 between MP 113.7 and MP 118.4 documented a long-standing pattern of WVCs involving multiple ungulate species. The dataset contained records spanning 2006 through 2025, with each entry noting the date, species, sex, age class, lane, and cause of death. As shown in the dataset, mule deer represented the majority of mortalities.

Most carcasses were attributed to WVCs, consistent with repeated entries listing "COLLISION" as the cause of death. Fence-type codes varied across the corridor, including combinations such as "05 = Comb WW & BW" and "07 = 3 & 4 BW," suggesting that animals encountered a mix of fencing conditions or transitions. Some records indicated areas without effective fencing, such as the 2025 entry reading "09 = Other, OPEN RANGE," which highlighted locations where wildlife had unrestricted access to the roadway.

Carcass occurrences were distributed throughout the segment, with dense clusters around MP 114–116, where repeated mule deer and elk collisions were documented over multiple years. Both northbound and southbound lanes recorded mortalities, indicating that animals attempted crossings in both directions.

Overall, the carcass data demonstrated persistent WVC along this portion of ML10, involving multiple species and age classes over nearly two decades. These patterns underscored the need for targeted mitigation measures, particularly fencing improvements and dedicated crossing infrastructure to reduce collision risk and improve wildlife movement across the corridor.

3.8.4. Colorado Carcass Data

Colorado's carcass dataset documented wildlife mortalities statewide from 2010 through 2024, capturing long-term patterns in WVCs across multiple species. Table 3-4 provides the Colorado carcass data summary. As shown in Table 3-4, deer consistently represented the highest number of carcasses each year. For example, 2,847 deer were recorded in 2010, and 3,897 were recorded in 2024 indicating persistent conflict between deer movement corridors and roadway networks. Elk also appeared regularly, with annual counts ranging from 250 in 2012 to 635 in 2024, demonstrating that larger ungulates were frequently involved in collisions as well.

The dataset showed notable increases in several species over time. Bear carcasses rose sharply in later years, with 245 recorded in 2022 and 219 in 2024, compared to only 13 in 2010. Moose mortalities also increased, with 59 recorded in 2022 and 62 in 2024, reflecting expanding populations and shifting habitat use. Occasional records of bighorn sheep, mountain goats, and pronghorns were also present, such as the 30 bighorn sheep in 2023 and 90 pronghorn in 2024, highlighting the diversity of species affected.

Across the full 15-year dataset, Colorado recorded 48,763 deer, 5,446 elk, 853 bears, 204 moose, and 17,963 animals categorized as "Other." These totals underscored the scale of wildlife-vehicle conflict statewide and demonstrated that multiple species were impacted across a wide range of habitats and roadway types.

Table 3-4 Colorado Carcass Data Summary

Year	Bear	Bighorn	Deer	Elk	Lion	Moose	Mountain Goat	Pronghorn	Other
2010	13	0	2,848	289	2	3	0	39	1,435
2011	12	3	2,889	349	3	9	0	37	1,447
2012	26	0	2,764	250	2	4	0	27	1,118
2013	11	1	2,446	265	0	5	0	10	1,026
2014	24	1	2,581	261	2	6	0	22	1,081
2015	21	0	3,241	281	6	6	0	17	1,423
2016	13	2	3,927	421	2	7	0	33	1,290
2017	14	3	3,572	308	6	12	0	27	1,303
2018	14	5	3,119	292	9	10	0	23	1,014
2019	18	1	2,740	323	4	11	0	33	819
2020	25	1	3,449	327	3	9	0	48	1,107
2021	21	0	3,729	354	2	16	0	47	1,015
2022	245	19	4,016	569	47	59	0	82	1,307
2023	177	30	3,522	524	59	63	2	57	1,141
2024	219	23	3,897	635	56	62	0	95	1,422
Grand Total	853	89	48,764	5,449	204	282	2	597	17,965

3.9. Migration Zone

Wildlife-fencing, crossing structures, and other mitigation measures are most effective when placed where animals naturally travel. Migration data shows that infrastructure investments align with actual movement behavior rather than assumptions. Because migration routes often cross state boundaries, using standardized corridor datasets shows that analyses remain comparable across jurisdictions. By combining migration corridor layers with roadway, fencing, and WVC datasets, the analysis captures both the transportation and ecological dimensions of collision risk. This integration is essential for developing mitigation strategies that are not only effective but also aligned with wildlife behavior and habitat connectivity needs.

Migration corridor GIS files were obtained from the respective wildlife division of each study state. These GIS layers provided critical spatial data for understanding seasonal wildlife movement patterns, particularly for species such as mule deer, elk, and pronghorn. Migration corridors were identified by the wildlife division by attaching compact GPS tracking devices to wildlife, enabling the movement patterns of wildlife to be tracked over time. The maps shown in Figures 3-18 through 3-21 provide the migration corridor locations across all the study states of Colorado (Figure 3-18), Utah (Figure 3-19), Idaho (Figure 3-20) and then then study-wide, including Nevada (Figure 3-21), respectively. About 22% of all WVCs occurred near migration zones.

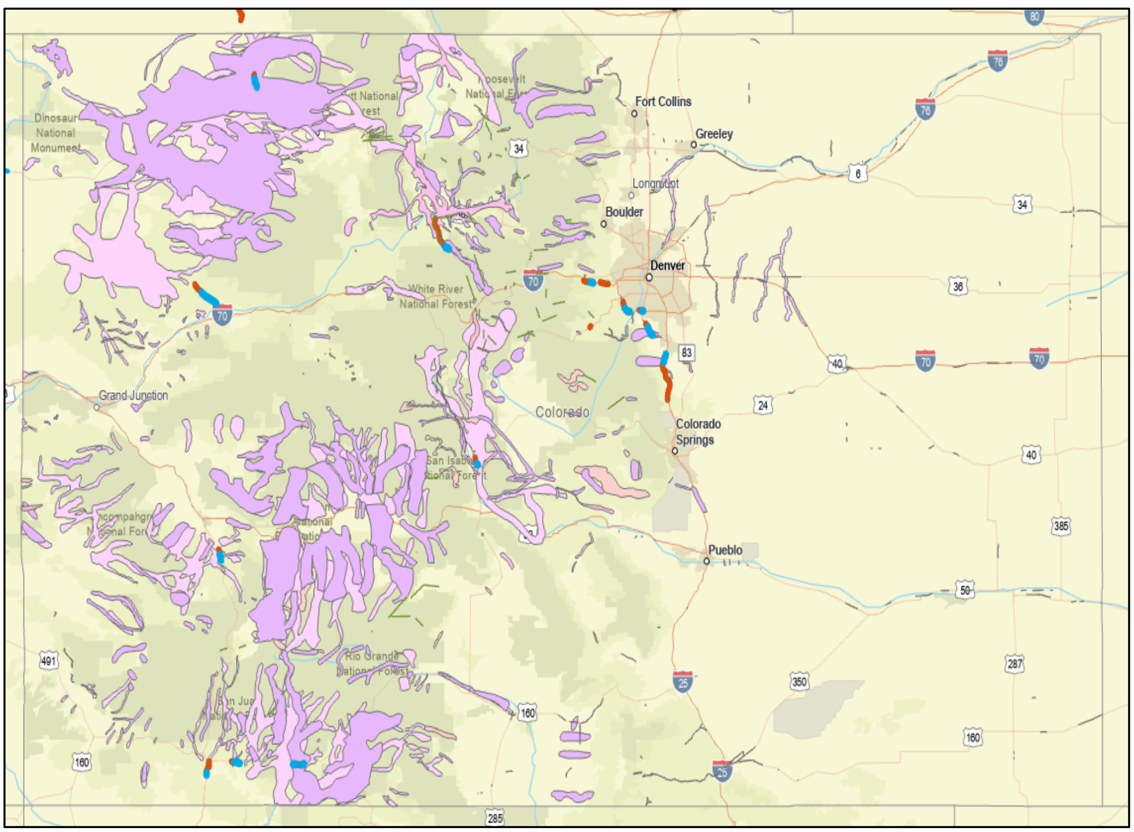


Figure 3-18 Colorado wildlife migration zones

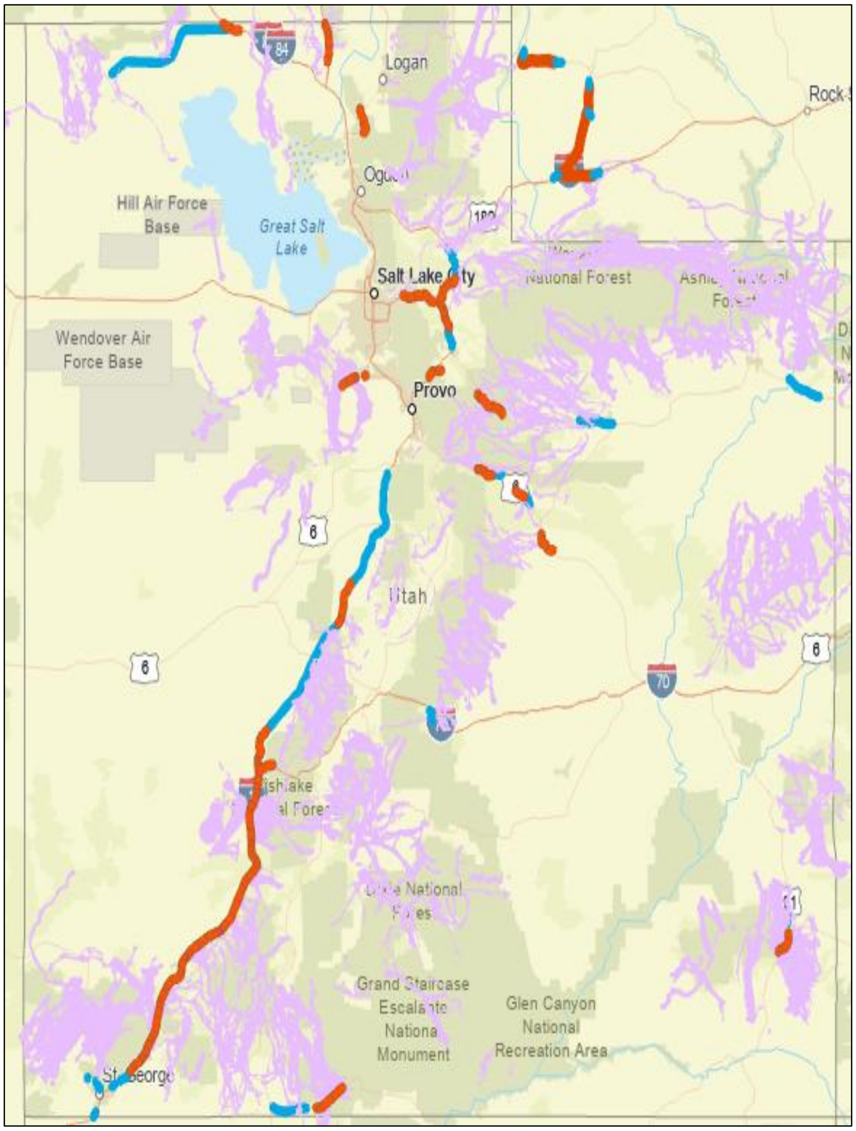


Figure 3-19 Utah wildlife migration zones

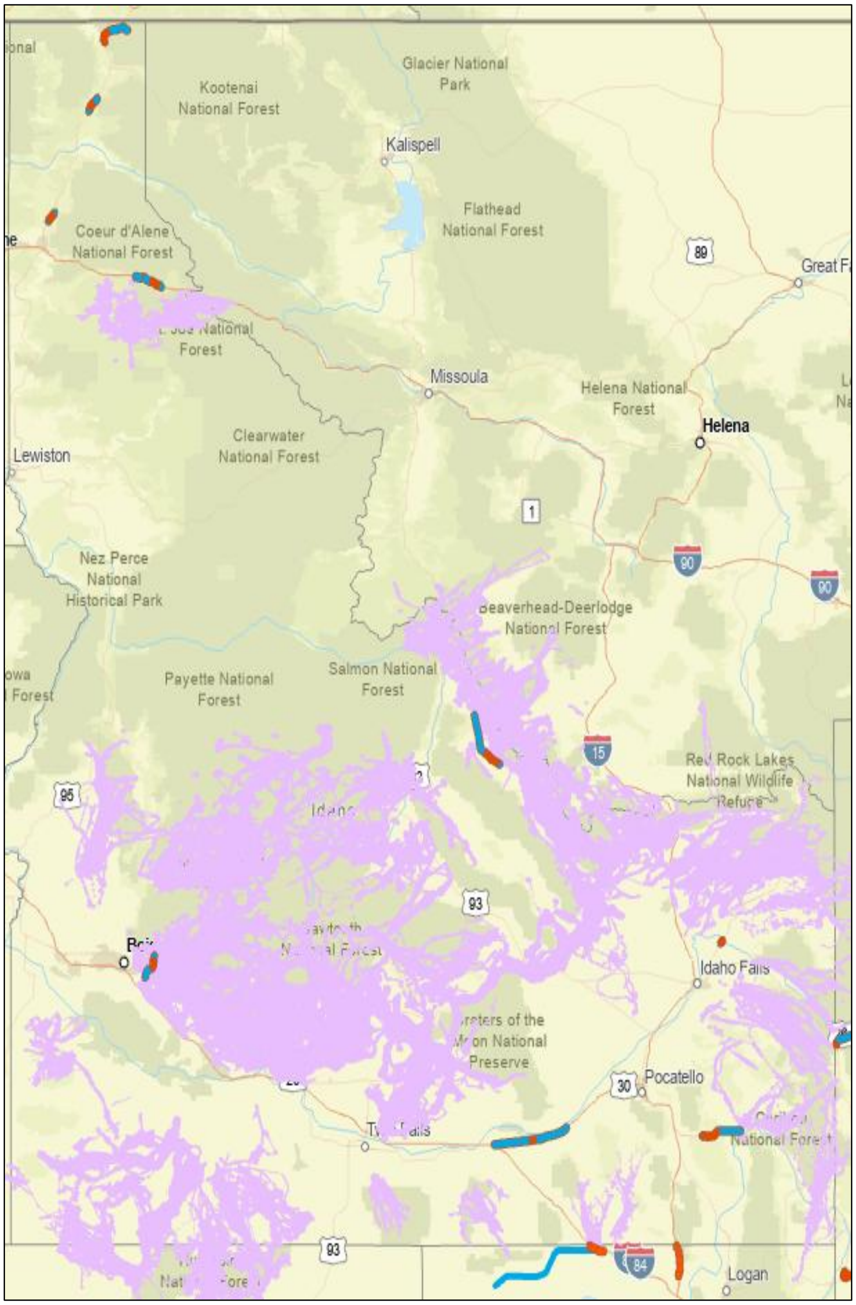


Figure 3-20 Idaho wildlife migration zones

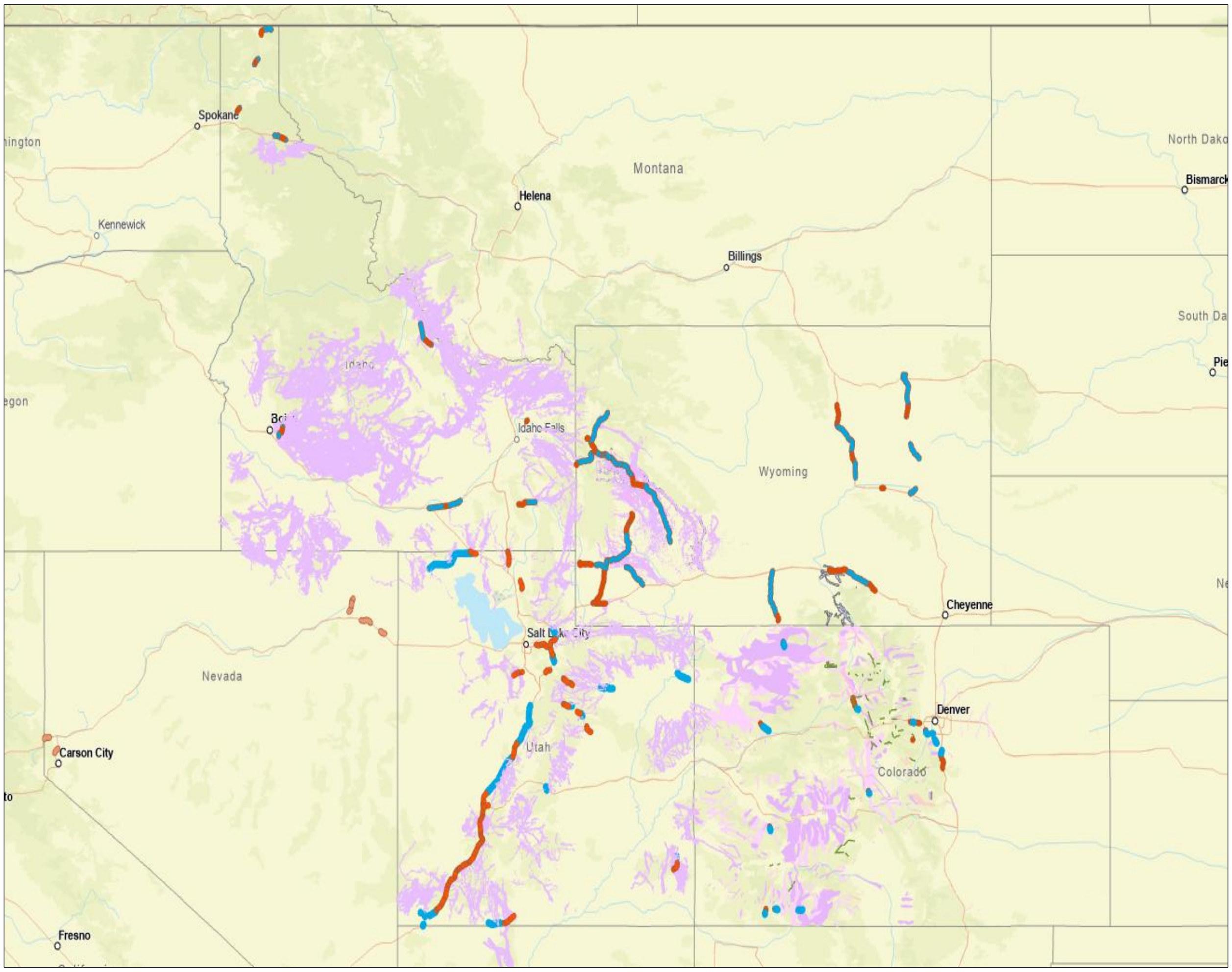


Figure 3-21 Study-wide wildlife migration zones

4. Methodology and Results

4.1. Overview

This chapter outlines the statistical methods used in the study and provides crash reduction results, including the Safety Performance Functions (SPFs) and CMFs. SPFs are statistical models that estimate the expected number of crashes at a site based on traffic volume and roadway characteristics. SPFs represent the baseline or "normal" crash frequency for a given facility type under typical conditions. They are commonly developed using negative binomial regression or machine-learning methods and are used in network screening, before–after evaluations, and EB analyses. A CMF is a multiplicative factor used to estimate the expected change in crash frequency after implementing a specific countermeasure. A CMF less than 1.0 indicates a reduction in crashes, while a CMF greater than 1.0 indicates an increase. CMFs are used in safety analysis, benefit–cost evaluations, and project prioritization to quantify the effectiveness of treatments such as wildlife-fencing, rumble strips, or roadway lighting.

4.2. Descriptive Statistics

A before and after comparison of WVCs was made for fencing treatment sites. Prior to wildlife-fencing installation, treatment segments experienced an average of 190 total WVCs per year, including 18 fatal and injury crashes and 173 PDO crashes as shown in Table 4-1. After installation, these averages dropped sharply to 45 total crashes, with 6 KABC crashes and 39 PDO crashes, reflecting substantial reductions across all severity levels. The dataset includes an average of 8.67 years of before-period data and 5.16 years of after-period data, with some sites contributing as few as one year and others up to 14 years of observations. Approximately 38% of the sites are located within designated migration zones, and 24% are in urban areas, indicating a mix of ecological and roadway contexts. Traffic volumes vary widely, with before-period AADT ranging from 1,055 to 78,250 (mean 14,368) and after-period AADT ranging from 818 to 82,750 (mean 16,823), reflecting both low-volume rural highways and high-volume regional corridors. Treatment segment lengths vary, from 0.12 miles to 19.0 miles, with an average length of 4.46 miles, demonstrating the diversity of fencing project scales included in the analysis. Together, these characteristics highlight the breadth of conditions represented in the study and support the robustness and generalizability of the resulting CMFs and SPFs.

Between 2012 and 2019, control sites experienced a total of 4,521 wildlife-vehicle collisions, including 390 fatal and injury (KABC) crashes and 4,131 PDO crashes, reflecting the predominance of non-injury outcomes typical of WVC patterns. Approximately 57% of the control sites are located within migration zones, a higher proportion than the treatment sites, indicating that control corridors intersect important wildlife movement areas. Urban segments account for 23% of the control network, similar to the treatment group, ensuring comparability in land-use context. Traffic volumes vary widely, with AADT values ranging from 292 to 94,000 and a mean of 22,054, demonstrating that the control network includes both low-volume rural highways and high-volume regional corridors as shown in Table 4-3. The total roadway length represented by the control sites is substantial 766 miles, with individual segments ranging from 0.1 to 44 miles providing a diverse and statistically robust reference group. These characteristics ensure that the control sites offer an appropriate and representative comparison for evaluating the safety effectiveness of wildlife-fencing installations.

Table 4-1 Descriptive Statistics for Study-Wide Treatment Segments – Yearly Crashes (148 Treatment Sites Total)

Variable	Total Before Yearly Crashes	Total After Yearly Crashes
Average Total Crashes per year	190	45
Average KABC Crashes per year	17	6
Average PDO crashes per year	173	39

Table 4-2 Descriptive Statistics for Study-Wide Treatment Segments – Mean, Minimum, and Maximum

Variable	Mean	Min	Max
Number of before years	8.67	1	14
Number of after years	5.16	1	13
Migration Zone	0.38	0	1
Urban	0.24	0	1
AADT before	14,368	1055	78,250
AADT after	16,823	818	82,750
Length in Miles	4.46	0.12	19

Table 4-3 Descriptive Statistics for Control Segments – Total Crashes (453 Control Sites Total)

Variable (2012-2019)	Total Crashes
Total WVCs	4,521
KABC WVCs	390
PDO WVCs	4,131

Table 4-4 Descriptive Statistics for Control Segments — Mean, Minimum, and Maximum

Variable (2012-2019)	Mean	Minimum	Maximum
Migration Zone	0.57	0	1
Urban	0.23	0	1
AADT	22,054	292	94,000
Length in Miles	766	0.1	44

4.3. Before and After Crash Evaluation

An observational before-and-after study using EB methodology was conducted to evaluate the safety effect of wildlife-fencing (Hauer et al., 1997). The effectiveness is calculated by comparing the observed crashes to the expected crashes after the treatment is installed. SPF models were developed for predicted wildlife crashes, which were grouped into models for “total”, “fatal and injury”, and “property damage only” crashes. The EB method accounts for regression-to-the-mean effects, the observed changes in crash frequency in the before and after periods, and changes in traffic and roadway characteristics (Park et al., 2016).

A comparison was made of segments before and after wildlife-fencing installations. Study segments averaged 190 WVCs per year before fencing, which dropped to 45 WVCs per year after installation, representing a 76% decrease. Injury crashes (KABC) declined from 18 to 6 per year, a 67% reduction, while PDO crashes fell from 173 to 39 per year, marking a 77% decrease. These findings demonstrate that wildlife-fencing significantly improved roadway safety by reducing the frequency of WVCs.

Table 4-5 Before and After WVC and Carcass Frequency Per Year

Crash Type (2010-2024)	Before reports per year	After reports per year	% Decrease
Average Total Crashes per year	190	45	76%
Average KABC Crashes per year	7	6	67%
Average PDO crashes per year	173	39	77%

4.4. Safety Performance Functions

An SPF is a crash prediction model that relates the crash frequency to traffic and other parameters. Data from the control sites and before period of the treatment segments was used to estimate the SPFs. The estimated SPF predicts the crash frequency that would have occurred without the treatment (Hauer et al., 1997). The predicted crash frequency is compared to the observed after period crash counts to develop a CMF.

SPFs were developed using negative binomial (NB) generalized linear models (GLM) (Park et al., 2016). The NB or the Poisson-gamma regression model is an extension of a Poisson model that addresses the over-dispersion in the data. The NB model assumes that the Poisson parameter (λ_i) follows a gamma probability distribution and the probability distribution function of the NB model for y_i, crashes occurring on segment i, can be written as equation 1.

$$f(y_i) = \frac{\Gamma(y_i+\phi)}{\Gamma(y_i+1)\Gamma(\phi)}\left(\frac{\phi}{\phi+\lambda_i}\right)^{\phi}\left(\frac{\lambda_i}{\phi+\lambda_i}\right)^{y_i} \quad (1)$$

where, (Γ) is a gamma function, and ϕ is the dispersion factor.

If α, which is a function of (1/ϕ), is the over-dispersion factor and is significantly greater than zero, the data is over-dispersed. If α is equal to zero, the NB reduces to the Poisson distribution, and the mean number of crashes on segment i. λ_i, is a linear function of the covariates. The NB model is derived from rewriting the functional form of the Poisson parameter for each observation i, specified as equation 2.

$$\lambda_i = \mathrm{EXP}(\beta X_i + \varepsilon_i) \quad (2)$$

where, $\mathrm{EXP}(\varepsilon_i)$ is the gamma-distributed error term with mean 1 and variance α.

The addition of this term allows the variance to differ from the mean. The variance can be calculated using equation 3.

$$\mathrm{Var}(y_i) = \lambda_i + \frac{\lambda_i^2}{\phi} \qquad \text{or} \qquad \mathrm{Var}(y_i) = \lambda_i + \alpha\lambda_i^2 \tag{3}$$

Measures of goodness-of-fit, including Log-Likelihood and Akaike Information Criterion (AIC), were used to ascertain the best fitted model. The best fitted model that displayed the maximum value of the log-likelihood function was chosen to obtain the parameter estimates that made the data most likely. AIC value was used to compare the performance of the GLMs. The preferred model is the one with the minimum AIC value. The AIC value is evaluated using equation 4.

$$AIC = 2k - 2Ln\ (L) \tag{4}$$

where, k = The number of estimated parameters in the model, and L = The maximum value of the likelihood function for the model.

The SPFs developed for this study use overall data to quantify how roadway, environmental, and geographic factors influence WVC frequency across the treatment corridors. For total WVCs, the SPF shows that crash frequency increases with higher traffic volumes (LnAADT) and in designated migration zones, while urban roadway contexts are associated with fewer WVCs. The positive coefficients for Utah and Colorado indicate that, after controlling for roadway and traffic characteristics, these states experience higher WVC frequencies than the baseline. The combined data of Wyoming and Idaho served as the baseline reference as both these states indicator variables were not significant in the model and Nevada was not used in the model as crash data were not available for Nevada. For fatal and injury WVCs, the model identifies traffic volume and segment length as key predictors, with longer roadway segments and higher AADT contributing to increased severe crash likelihood; the Utah indicator shows a marginally higher severe crash baseline compared to the reference.

The PDO WVC model mirrors the total crash model, with migration zones and higher traffic volumes increasing PDO crash frequency, and urban areas showing significantly fewer PDO WVCs. The dispersion parameters (ϕ = 0.544–0.648) confirm that the NB model form appropriately accounts for overdispersion in the crash data. Collectively, these SPFs provide a robust statistical foundation for understanding WVC patterns and for predicting expected crash frequencies under varying roadway and environmental conditions. The parameter estimates in the SPF models are supported by generally low standard errors and statistically significant p values, indicating stable and reliable relationships between the predictors and WVC outcomes. In the Total WVC model, key predictors such as LnAADT (SE = 0.0828, $p = 0.001$), Migration Zone (SE = 0.1602, $p = 0.004$), and Urban (SE = 0.2652, $p = 0.004$) all show strong statistical significance, meaning these variables consistently influence crash frequency across sites. The state indicators for Utah and Colorado also have very small standard errors (0.2431 and 0.2395) and highly significant p values ($p < 0.001$), reinforcing the robustness of these geographic effects. In the Fatal and Injury WVC model, LnAADT ($p = 0.0331$) and LnLength ($p < 0.0001$) are statistically significant with small standard errors, demonstrating that traffic volume and segment length are reliable predictors of severe crashes. The Utah indicator is marginal ($p = 0.0575$), suggesting a possible but less certain effect. For the PDO WVC model, LnAADT, Migration Zone, Urban, Utah, and Colorado all have p values below 0.01 and standard errors in the 0.16–0.27 range, indicating precise estimates and strong evidence that these variables meaningfully affect PDO crash frequency. Overall, the combination of low standard errors and statistically significant p values across most predictors confirms that the models are well fitted and that the included variables are important contributors to WVC occurrence.

Table 4-6 shows the final models that were developed for overall SPFs, and Table 4-7 shows the parameter estimates and model statistics for the overall SPFs.

Table 4-6 Final Models Developed for Overall SPFs

Crash Type	Safety Performance Functions (SPFs)	Dispersion Parameter* (ϕ)
Total WVCs	exp{−1.3266+0.2798ln(AADT)+0.4641(MigrationZone) −0.7718(Urban)+1.0208(Utah)+1.5077(Colorado)}	0.648
Fatal and injury WVCs	exp{−2.2472+0.20484ln(AADT)+0.67617ln(Length) +0.5538(Utah)}	0.544
PDO WVCs	exp{−1.5854+0.28652ln(AADT)+0.51479(MigrationZone) −0.8725(Urban)+1.13708(Utah)+1.58689(Colorado)}	0.647
Carcass	exp{−6.3502+ 1.0142ln(AADT)+ 0.8477 (MigrationZone)	0.047

Table 4-7 Parameter Estimates and Model Statistics for Overall SPFs

Parameter	**SPFs-Estimate (β)**	**SPFs-Std. Error**	**SPFs-Z-value**	**SPFs-P-Value**	**AIC**
Total WVCs	--	--	--	--	--
(Intercept)	-1.3266	0.7743	-1.71	0.087	2087
LnAADT	0.2798	0.0828	3.379	0.001	2087
Migration Zone	0.4641	0.1602	2.896	0.004	2087
Urban	-0.7718	0.2652	-2.91	0.004	2087
Utah	1.0208	0.2431	4.198	0.000	2087
Colorado	1.5077	0.2395	6.295	0.000	2087
*α**	0.648	--	--	--	--
Fatal and Injury WVCs	--	--	--	--	--
(Intercept)	-2.2472	0.88696	-2.53	0.0113	777
LnAADT	0.20484	0.09611	2.131	0.0331	777
LnLength	0.67617	0.07878	8.583	0.0000	777
Utah	0.5538	0.2916	1.899	0.0575	777
*α**	0.544	--	--	--	--
PDO WVCs	--	--	--	--	--
(Intercept)	-1.5854	0.78058	-2.03	0.042	2106
LnAADT	0.28652	0.08345	3.433	0.001	2106

Parameter	SPFs-Estimate (β)	SPFs-Std. Error	SPFs-Z-value	SPFs-P-Value	AIC
Migration Zone	0.51479	0.16258	3.166	0.002	2106
Urban	-0.8725	0.26919	-3.24	0.001	2106
Utah	1.13708	0.24477	4.645	0.000	2106
Colorado	1.58689	0.24228	6.55	0.000	2106
*α**	0.647	--	--	--	--

4.5. Calculation of Before and After Predicted Crashes

SPFs were used to calculate annual predicted crashes for both the before and after periods per unit length for each of the treatment sites. The relative weight given to the before predicted crashes was calculated using the dispersion factor from the NB model as in equation 5.

$$w = \frac{1}{(1+\alpha\times N_{bp})} \qquad (5)$$

where, α = estimated NB model over dispersion parameter; N_{bp} = before predicted crash frequency

An estimate of the expected number of crashes before implementation of treatment at each treatment site (shown in equation 6) was computed using the developed SPFs.

$$N_{eb} = \left(w \times N_{bp}\right) + (1 - w) \times (N_b) \qquad (6)$$

where, N_{eb} = expected annual before crash frequency; w = weight; N_b = annual crash counts during the before period

4.6. Calculating Crash Modification Factor

The SPFs developed based on the control group were used to account for traffic volume changes. SPFs were calibrated to each period, and these calibration factors (multipliers) reflect differences in crash frequency and traffic volume between the before and after periods. The correction is done using the ratio of annual predicted crashes calculated from the changes of AADT in the before-after periods. The ratio was calculated using equation 7.

$$R_1 = \frac{(N_{ap})}{(N_{bp})} \qquad (7)$$

where, N_{ap} = after predicted crash frequency; N_{bp} = before predicted crash frequency

The expected number of after-period crashes that would have occurred without wildlife-fencing was computed using equation 8.

$$N_{ea} = R_1 \times (N_{eb}) \tag{8}$$

where, N_{ea} = expected after crash frequency

Changes in traffic volumes are reflected in the EB method leaving other factors such as weather, vehicle performance, and driver behaviors unchanged. Thus, the number of crashes per site that would have occurred in the after period without the countermeasure is given by N_{EA}.

$$N_{EA} = A \times (N_{ea}) \tag{9}$$

where, A = length of the after period in years

The variance of N_{EA} is calculated by equation 10.

$$Var(N_{EA}) = \frac{\{(N_{eb}) \times (R_1 \times A)^2\}}{\left\{B + \left(\frac{\alpha}{N_{bp}}\right)\right\}} \tag{10}$$

where, B = length of the before period in years

The ratio of the total number of observed crashes in the after period ($\sum N_a$) to the total number of expected crashes in the after period had there been no countermeasure ($\sum N_{EA}$) was calculated. This would be a biased estimate of the CMF. The ratio is given by equation 11.

$$R_2 = \frac{(\sum N_a)}{(\sum N_{EA})} \tag{11}$$

where, N_a = crash counts during the after period

CMFs for the wildlife-fence countermeasure were calculated using equation 12.

$$CMF(\theta) = \frac{R_2}{\left\{1 + \frac{\{\sum Var(N_{EA})\}}{(\sum N_{EA})^2}\right\}} \tag{12}$$

The variance of CMF(Θ) was calculated using equation 13.

$$Var(\theta) = \frac{\theta^2 \times \left[\left\{\frac{Var(\sum N_a)}{(\sum N_a)^2}\right\} + \left\{\frac{\sum Var(N_{EA})}{(\sum N_{EA})^2}\right\}\right]}{\left\{1 + \frac{\{\sum Var(N_{EA})\}}{(\sum N_{EA})^2}\right\}} \tag{13}$$

The standard error, which is the standard deviation of a sample mean, provides a measure of certainty (or uncertainty) in the CMF. A relatively small standard error, with respect to the magnitude of the CMF estimate, indicates greater certainty in the estimate of the CMF, while a relatively large standard error indicates less certainty in the estimate of the CMF. The standard error is used in the calculation of the confidence interval. The standard error is simply the square root of the variance as shown in equation 14.

$$S.E.(\Theta) = \sqrt{Var(\Theta)} \quad (14)$$

4.6.1. CMF Results for All States

An observational before-and-after study using an EB methodology was conducted. Hauer concluded that EB before-after analysis is a statistically well-accepted method to evaluate safety effects of treatments. The safety effectiveness of a treatment can be calculated by comparing the observed and expected number of crashes in the after period. The EB method can account for regression-to-the-mean (RTM) effects, the observed changes in crash frequency in the before and after periods, and the changes of traffic and roadway characteristics (Park et. al, 2016). Several recent studies relied on the EB method to develop CMFs for several crash countermeasures (Hallmark et. al., 2020, Hallmark et. al. 2016, Goswamy et. al. 2023). CMFs were determined for Total WVCs, Fatal and Injury WVCs, and PDO WVCs for all states combined, as well as for the individual states of Utah and Colorado. Results are shown in Table 4-8. State-specific CMF results for Idaho, Nevada, and Wyoming could not be calculated because fewer than 34 sites from each state were available.

Overall, the data strongly supports wildlife-fencing as a highly effective safety countermeasure with consistent impact across crash types. Wildlife-fencing led to a greater reduction in WVCs in migration areas compared to all areas. These findings support continued investment in targeted safety interventions across migration corridors.

The EB evaluation across all participating states shows that wildlife-fencing is associated with substantial and statistically reliable reductions in wildlife–vehicle conflicts and carcass occurrences. The Total WVC CMF of 0.27 indicates a 73% reduction in overall wildlife-vehicle crashes following installation. This effect is supported by a low standard error (0.019) and a narrow 95% confidence interval (0.23, 0.30), demonstrating strong precision and consistency across states.

For severe crashes, the KABC WVC CMF of 0.12 reflects an 88% reduction in fatal and injury-related wildlife crashes. This is the largest effect observed among the crash-based metrics, suggesting that fencing is particularly effective at preventing high-severity events. The confidence interval (0.08, 0.16) confirms that the true effect is well below 1.0 with high statistical certainty.

The PDO WVC CMF of 0.28 corresponds to a 72% reduction in property-damage-only wildlife crashes. This result is consistent with the total-crash findings and indicates that fencing reduces both minor and major crash outcomes at similar magnitudes. The standard error (0.022) and confidence interval (0.24, 0.33) again demonstrate strong reliability.

The carcass CMF of 0.13 indicates an 87% reduction in observed carcasses, reflecting a major decrease in wildlife presence on or near the roadway. The extremely small standard error (0.005) and tight confidence interval (0.12, 0.15) show that this estimate is highly precise. Because carcass counts are often less sensitive to reporting variability than crash data, this result reinforces the conclusion that wildlife-fencing effectively excludes animals from the roadway corridor.

Across all metrics, total crashes, severe crashes, PDO crashes, and carcasses, the results consistently show large, statistically robust reductions. The corresponding CRFs (0.72–0.88) further confirm that wildlife-fencing is a highly effective mitigation strategy across diverse roadway and environmental conditions represented in the multi-state dataset.

Table 4-8 CMF Statistics for All States Together

Empirical Bayes	Total WVCs	KABC WVCs	PDO WVCs	Carcass
CMF	0.27	0.12	0.28	0.13
CRF	0.73	0.88	0.72	0.87
Standard Error	0.019	0.020	0.022	0.005
95% confidence interval for CMF	(0.23, 0.30)	(0.08, 0.16)	(0.24, 0.33)	(0.12,0.15)

4.6.2. CMF Results for Utah

A CMF of 0.25 for total WVCs was estimated showing that wildlife-fencing has the potential to reduce 75% of WVCs. Table 4-9 shows the CMF and CRF results. CMFs for fatal and injury crashes and PDO crashes were also investigated. The CMF for fatal and injury crashes was found to be 0.15, showing that wildlife-fencing has a positive effect in reducing fatal and injury crashes by 85%. Similarly, it was observed that the CMF for the PDO crashes was 0.26, indicating a crash reduction of 74%. Results show that wildlife-fencing can be effective in reducing wildlife-related crashes.

Table 4-9 CMF Statistics for Utah

Empirical Bayes	Total WVCs	KABC WVCs	PDO WVCs	Total WVCs in Migration Area
CMF	0.25	0.15	0.26	0.13
CRF	0.75	0.85	0.74	0.87
Standard Error	0.024	0.039	0.026	0.013
95% confidence interval for CMFs	(0.20, 0.30)	(0.08, 0.23)	(0.21, 0.31)	(0.11, 0.16)

4.6.3. CMF Results for Colorado

EB results for Colorado demonstrate that wildlife-fencing is highly effective in reducing wildlife-vehicle collisions across all severity levels. Prior to treatment, the EB-expected number of crashes was 710 total WVCs, including 133 KABC and 596 PDO crashes. After fencing installation, observed crashes dropped to 206 total, 26 KABC, and 180 PDO, reflecting substantial reductions. The resulting CMFs were 0.29 for total WVCs, 0.20 for KABC crashes, and 0.30 for PDO crashes, corresponding to reductions of 71%, 80%, and 70%, respectively. These estimates are supported by low standard errors (0.029–0.046) and narrow 95% confidence intervals (0.23, 0.35) for total crashes, (0.10, 0.29) for KABC, and (0.24, 0.37) for PDO indicating strong statistical precision and reliability, see Table 4-10. Overall, the Colorado-specific results reinforce the broader study findings, confirming that wildlife-fencing provides consistent and substantial safety benefits across diverse roadway and ecological conditions.

Table 4-10 CMF Statistics for Colorado

Empirical Bayes	Total WVCs	KABC WVCs	PDO WVCs

CMF	0.29	0.20	0.30
CRF	0.71	0.80	0.70
Standard Error	0.029	0.046	0.032
95% confidence interval for CMFs	(0.23,0.35)	(0.10, 0.29)	(0.24,0.37)

4.7. Benefit-Cost Analysis

An economic benefit-cost analysis of the treatment segments was performed with all states combined. The analysis included a benefit-cost ratio (BCR) calculation that divides the project total discounted benefits by the total discounted costs. A BCR greater than 1.0 indicates a project is expected to deliver positive net benefits. Cost per foot of fencing was obtained for some states. The average cost represented by installing wildlife-fencing was calculated to be $29.25 a linear foot. The cost comparison across wildlife-mitigation projects shows substantial variation in the cost per linear foot of fencing and crossing infrastructure, reflecting differences in project type, terrain, project complexity, and construction requirements shown in Table 4-11.

Table 4-11 Average Wildlife-Fencing Installation Costs

Project Name	State	Cost per feet
I-86 Raft River Bridges	Idaho	$14.82
US-30 Fish Creek Pass Wildlife-Fence	Idaho	$14.70
SH-21 Lucky Peak Wildlife Undercrossing	Idaho	$22.86
SH-21 Cervidae Peak Wildlife Overcrossing	Idaho	$69.44
SH-28 Lemhi Wildlife Undercrossing Fencing	Idaho	$62.92
SH-28 Wildlife-Fence Extension	Idaho	$18.37
US-20 Lorenzo Bridge Wildlife Undercrossing	Idaho	$42.96
US-95 Chilco Wildlife Undercrossing	Idaho	$16.12
US-95 Copeland Fencing Extension	Idaho	$25.21
US-95 McArthur Lake Wildlife Undercrossing	Idaho	$21.09
Wildlife-fence on I-15 - PIN 20010	Utah	$27.00
I-15; Wildlife-Fencing, Phase 2 - PIN 16426	Utah	$8.00
US-40; Wildlife-fencing MP 58 to 81 - PIN 22804	Utah	$50.00
I-80; MP 145.4-146.9 Wildlife-fencing - PIN 22938	Utah	$16.00
Average Cost per linear feet	--	$29.25

The benefit–cost analysis for overall data demonstrates that wildlife-fencing provides substantial long-term economic value by preventing both fatal/injury (KABC) and PDO WVCs. The EB results indicate a crash modification factor (CMF) of 0.27 for total WVCs, corresponding to a 73% reduction, with a standard error of 0.019 and a 95% confidence interval of (0.23, 0.30). For fatal and injury (KABC) WVCs, the CMF was 0.12 corresponding to an 88% reduction, supported by a standard error of 0.020 and a 95% confidence interval of (0.08, 0.16). Property-damage-only (PDO) crashes showed a CMF of 0.28, representing a 72% reduction, with a standard error of 0.022 and a 95% confidence interval of (0.24, 0.33). Thus, across the 20-year analysis period, yearly fatal and injury (KABC) crashes decrease from approximately 18 to just over 2, resulting in an annual reduction of 15–17 severe crashes. When monetized, these avoided KABC crashes generate annual safety benefits ranging from $7.29 million in Year 1 to $8.02 million in Year 20, reflecting the high societal cost associated with injury crashes. PDO crashes show a similar pattern, decreasing from roughly 173 per year before fencing to about 51 after installation, yielding annual reductions of 126–139 PDO crashes. These avoided PDO crashes contribute an additional $2.35–$2.58 million in yearly benefits. Combined, the total annual monetary benefit grows from $9.64 million in Year 1 to $10.60 million in Year 20, demonstrating consistent and increasing economic returns over time. When discounted using the present-value ratios provided, the cumulative present value of benefits equals $149.7 million, resulting in a BCR of 2.6. This indicates that every $1 invested in wildlife-fencing returns more than $2.50 in safety benefits, confirming that fencing is a highly cost-effective mitigation strategy with substantial long-term savings for the transportation system and the public. Table 4-12 shows the benefit-cost ratio calculations over 20 years.

Table 4-12 Study-Wide 20 Year Benefit Cost Ratio

Year	Before Yearly KABC Crashes	After Yearly KABC Crashes	Reduction in KABC Crashes	Annual Monetary Value of KABC Crashes ($)	Before Yearly PDO Crashes	After Yearly PDO Crashes	Reduction in PDO Crashes	Annual Monetary Value of PDO crashes ($)	Total Benefit ($)	Present Value Ratio	Present Value Saved (Year 0) ($)
1	18.0	2.2	15.8	$7,292,102	173.0	46.7	126.3	$2,348,994	$9,641,096	0.971	$9,360,288
2	18.1	2.2	15.9	$7,328,563	173.9	46.9	126.9	$2,360,739	$9,689,302	0.943	$9,133,096
3	18.2	2.2	16.0	$7,365,206	174.7	47.2	127.6	$2,372,543	$9,737,748	0.915	$8,911,419
4	18.3	2.2	16.1	$7,402,032	175.6	47.4	128.2	$2,384,405	$9,786,437	0.888	$8,695,123
5	18.4	2.2	16.2	$7,439,042	176.5	47.7	128.8	$2,396,327	$9,835,369	0.863	$8,484,076
6	18.5	2.2	16.2	$7,476,237	177.4	47.9	129.5	$2,408,309	$9,884,546	0.837	$8,278,152
7	18.5	2.2	16.3	$7,513,618	178.3	48.1	130.1	$2,420,351	$9,933,969	0.813	$8,077,226
8	18.6	2.2	16.4	$7,551,186	179.1	48.4	130.8	$2,432,452	$9,983,639	0.789	$7,881,177
9	18.7	2.2	16.5	$7,588,942	180.0	48.6	131.4	$2,444,615	$10,033,557	0.766	$7,689,886
10	18.8	2.3	16.6	$7,626,887	180.9	48.9	132.1	$2,456,838	$10,083,725	0.744	$7,503,238
11	18.9	2.3	16.7	$7,665,021	181.8	49.1	132.7	$2,469,122	$10,134,143	0.722	$7,321,121
12	19.0	2.3	16.7	$7,703,347	182.8	49.3	133.4	$2,481,467	$10,184,814	0.701	$7,143,424
13	19.1	2.3	16.8	$7,741,863	183.7	49.6	134.1	$2,493,875	$10,235,738	0.681	$6,970,040
14	19.2	2.3	16.9	$ 7,780,573	184.6	49.8	134.7	$2,506,344	$10,286,917	0.661	$6,800,864
15	19.3	2.3	17.0	$7,819,475	185.5	50.1	135.4	$2,518,876	$10,338,351	0.642	$6,635,794
16	19.4	2.3	17.1	$7,858,573	186.4	50.3	136.1	$2,531,470	$10,390,043	0.623	$6,474,731
17	19.5	2.3	17.2	$7,897,866	187.4	50.6	136.8	$2,544,128	$10,441,993	0.605	$6,317,578
18	19.6	2.4	17.2	$7,937,355	188.3	50.8	137.5	$2,556,848	$10,494,203	0.587	$6,164,238
19	19.7	2.4	17.3	$7,977,042	189.2	51.1	138.2	$2,569,633	$10,546,674	0.570	$6,014,621
20	19.8	2.4	17.4	$8,016,927	190.2	51.4	138.8	$2,582,481	$10,599,408	0.554	$5,868,635

Benefit-Cost Ratio: 2.5859

Total Present Value Saved: $149,724,726

5. Conclusions

5.1. Overview

This chapter summarizes the findings of the study, explains data and evaluation methods along with the results and conclusions, and addresses the objectives of the research.

5.2. Summary

WVCs are a significant safety concern and a major source of wildlife mortality. Wildlife-fencing is a safety countermeasure to mitigate WVCs and enhance wildlife conservation efforts. The intent of this project was to establish a CMF for wildlife-fencing installation. The CMF was developed using the CMF Clearinghouse guidance regarding accuracy, precision, and general applicability of results. Common characteristics of a high-quality CMF include a statistically rigorous reference group, adequate sample size, diverse geographies and sites, small standard errors, and controls for potential bias.

Three separate SPF models were developed to evaluate factors associated with (1) total WVCs, (2) fatal and injury WVCs, and (3) PDO WVCs. Each model was estimated using a NB regression framework, and the AIC was used to compare model fit. The estimated coefficients, standard errors, and p-values are presented in the table. Across all three models, several consistent patterns emerged.

Traffic volume (AADT) was a strong and significant predictor of WVCs across all severity levels. Migration corridors were associated with higher crash frequencies, highlighting the importance of incorporating movement ecology into mitigation planning. Urban areas experienced fewer WVCs, reflecting reduced wildlife presence. State-level differences were evident, particularly for Utah and Colorado, suggesting variation in wildlife populations, roadway characteristics, or reporting practices. Segment length was especially important for predicting severe crashes. These models provide a quantitative foundation for identifying high-risk segments and prioritizing mitigation strategies such as fencing, crossing structures, and targeted hotspot treatments.

This study investigated the safety effectiveness of wildlife-fencing installed in Colorado, Idaho, Nevada, Utah, and Wyoming between 2011 and 2023. A total of 620 miles of treated sites and 766 miles of matched control sites were analyzed using SPFs and EB methods. Updated EB results indicate a CMF of 0.27 for total WVCs, corresponding to a 73% reduction, with a standard error of 0.019 and a 95% confidence interval of (0.23, 0.30). For fatal and injury (KABC) crashes, the CMF was 0.12, indicating an 88% reduction, supported by a standard error of 0.020 and a 95% confidence interval of (0.08, 0.16). PDO crashes showed a CMF of 0.28, representing a 72% reduction, with a standard error of 0.022 and a 95% confidence interval of (0.24, 0.33). These narrow confidence intervals and low standard errors reinforce the statistical reliability and precision of the findings. The Colorado analysis provided clear and compelling evidence that wildlife-fencing delivered substantial safety benefits across all crash severities. The EB comparison showed that observed crashes after installation were far lower than the EB-expected values, resulting in CMFs of 0.29 for total WVCs, 0.20 for KABC crashes, and 0.30 for PDO crashes. These corresponded to reductions of 71%, 80%, and 70%, respectively demonstrating that fencing was highly effective not only in reducing overall crash frequency but also in preventing the most severe outcomes. The low standard errors and narrow 95% confidence intervals further confirmed the precision and reliability of these estimates. For Utah-specific CMFs, the study evaluated 54 treated sites (138 miles) with wildlife-fencing installations and 90 control sites (583 miles) with comparable characteristics

The study results confirmed the effectiveness of wildlife-fencing at improving roadway safety, and that wildlife-fencing performs effectively across diverse roadway and ecological contexts and represents a strong return on investment for agencies seeking to reduce WVCs and enhance motorist safety. Traffic volume, wildlife herd size, migration area usage type, and urban versus rural were included as explanatory variables in the study. A CMF of 0.25 for total wildlife related crashes was estimated showing that wildlife-fencing has the potential to reduce 75% of total WVCs. A CMF for fatal and injury crashes was also investigated and found to be 0.15, showing that wildlife-fencing has a significant effect in reducing fatal and injury crashes by 85%. Similarly, a CMF of 0.26 for the PDO crashes was calculated, indicating a crash reduction of 74%. Carcass data provided an independent validation of these crash-based findings. The carcass CMF of 0.13 indicates an 87% reduction in observed carcasses, with an exceptionally small standard error of 0.005 and a tight 95% confidence interval of (0.12, 0.15). This high precision reinforces that wildlife-fencing substantially reduces wildlife presence on or near the roadway, complementing the reductions observed in crash outcomes.

It was seen that wildlife-fencing creates a greater reduction (about 87%) in WVCs in sensitive migration areas compared to other areas because these areas concentrate on animal movement across roads, increasing the probability for WVCs. Low standard errors and narrow 95% confidence intervals reinforce the statistical reliability of the results. Overall, the data strongly supports wildlife-fencing as a highly effective safety countermeasure with consistent impact across all crash scenarios in this study. The economic analysis indicates that the implementation of wildlife-fencing will yield benefit to cost ratios of approximately 2.0 with a 3% discount rate.

6. Recommendations and Implementation

6.1. Recommendations

The results of this multi-state evaluation clearly demonstrate that wildlife-fencing is an effective and reliable countermeasure for reducing WVCs. With CMFs ranging from 0.12 to 0.30 across crash severities and consistently narrow confidence intervals, the evidence showed that fencing produced substantial reductions in total, injury, and PDO crashes. Based on these findings, agencies should prioritize the installation of wildlife-fencing along roadway segments with high traffic volumes, documented migration activity, and recurring WVC patterns. These areas consistently exhibited the highest crash frequencies in the SPF models, underscoring the importance of integrating movement of ecology into mitigation planning. Fencing should also be paired with wildlife undercrossings or overcrossings in locations where animal movement is highly concentrated, as the greatest reductions up to 87% were observed in sensitive migration zones. The CMFs developed in this study can be incorporated into statewide safety management systems, including Highway Safety Improvement Program (HSIP) project evaluations, benefit–cost analyses, and network screening processes, to support data-driven decision-making. Continued investment in wildlife-fencing is strongly recommended, as the economic analysis indicated a benefit–cost ratio of approximately 2.6, confirming that fencing is both an effective and cost-efficient strategy for improving roadway safety and supporting wildlife conservation.

6.2. Implementation Plan

Implementation of wildlife-fencing should begin with a systematic identification of high-risk corridors. Using the SPFs and CMFs developed in this study, agencies can screen statewide networks to pinpoint segments with elevated predicted crash frequencies, high AADT, or known migration pathways. Field verification should follow to confirm habitat connectivity, assess fencing feasibility, and identify any site-specific constraints. Early coordination with wildlife agencies, local governments, and landowners will be essential to ensure that fencing aligns with ecological needs and land-use considerations.

Once priority corridors are identified, agencies should proceed with project development and design. This phase should include engineering design of fencing alignments, tie-ins to crossing structures, and supporting features such as escape ramps and wildlife-friendly gates. Environmental review and permitting should be conducted in collaboration with wildlife biologists to minimize habitat fragmentation and ensure that fencing enhances, rather than restricts, wildlife movement. Cost estimation and funding allocation should incorporate the CMFs and benefit–cost ratios from this study to justify investment through HSIP, environmental mitigation programs, or other funding mechanisms.

Construction should be scheduled to minimize disruption to wildlife movement and roadway operations. Quality assurance during installation is critical to ensure that fencing height, mesh size, anchoring, and end treatments meet performance standards. After construction, agencies should implement a long-term monitoring program to track WVC trends, evaluate fencing condition, and identify any breach points or end-run issues. Adaptive management such as extending fencing, repairing damage, or adding crossing structures should be employed as needed to maintain long-term effectiveness. Regular reporting and periodic updates to CMFs will help refine future mitigation strategies and support ongoing improvements in roadway safety and wildlife conservation.

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